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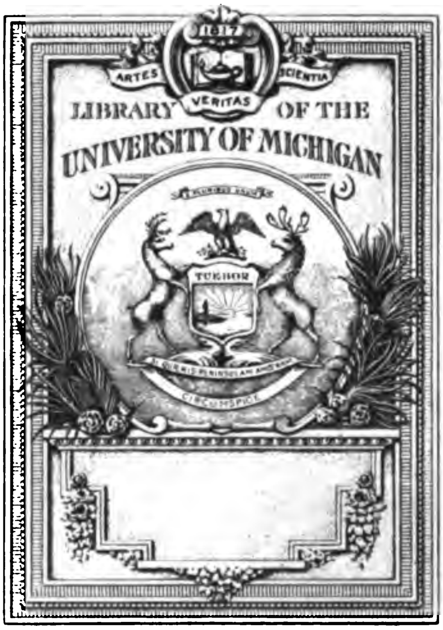
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REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY

OF MICHIGAN

FOR THE YEAR 1907

ALFRED C. LANE
STATE GEOLOGIST

BY AUTHORITY

LANSING, MICHIGAN.
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1908.

OCTOBER, 1908.

BOARD OF GEOLOGICAL SURVEY

1907

EX OFFICIO:

THE GOVERNOR OF THE STATE,
HON. F. M. WARNER, *President.*
THE PRESIDENT OF THE STATE BOARD OF EDUCATION,
HON. D. M. FERRY, JR., *Vice-President.*
THE SUPERINTENDENT OF PUBLIC INSTRUCTION,
HON. L. L. WRIGHT, *Secretary.*

BOARD OF SCIENTIFIC ADVISORS

PROF. W. B. BARROWS.
PROF. W. J. BEAL.
PROF. W. H. HOBBS.
PROF. L. L. HUBBARD.
PROF. F. C. NEWCOMBE.
PROF. J. REIGHARD.

198830

PERMANENT STAFF

LANSING

Alfred C. Lane, State Geologist.

W. F. Cooper, Assistant.

Harry R. Wight, Clerk.

HOUGHTON

A. H. Meuche, Engineer in Charge.

CONTENTS

Papers Included.

Page

ANNUAL REPORT OF THE STATE GEOLOGIST.

Table of contents 5

Index to same 27

FOUNDRY SANDS, BY HEINRICH RIES AND J. A. ROSEN.

Table of contents 37

Index to same 81

SUMMARY OF THE SURFACE GEOLOGY OF MICHIGAN, BY ALFRED C. LANE.

Table of contents 93

Index to same 145

A BIOLOGICAL SURVEY OF WALNUT LAKE, MICHIGAN, BY THOMAS L. HANKINSON AND OTHERS.

Table of contents 157

Index to same 273

NINTH ANNUAL REPORT

OF THE

STATE GEOLOGIST,

ALFRED C. LANE

TO THE

BOARD OF GEOLOGICAL SURVEY

FOR THE YEAR 1907.

GREAT SEAL OF THE STATE OF MICHIGAN A.D. MDCCCXXXV

BY AUTHORITY.

LANSING
WYNKOOP HALLENBECK CRAWFORD COMPANY, STATE PRINTERS
1908

BOARD OF GEOLOGICAL SURVEY

1907

EX OFFICIO:

THE GOVERNOR OF THE STATE,
HON. F. M. WARNER, *President.*

THE SUPERINTENDENT OF PUBLIC INSTRUCTION,
HON. L. L. WRIGHT, *Secretary.*

THE PRESIDENT OF THE STATE BOARD OF EDUCATION,
HON. D. M. FERRY, JUNIOR.

SCIENTIFIC ADVISERS.

Geologists.—Dr. L. L. Hubbard, Houghton; Prof. W. H. Hobbs, Ann Arbor.
Botanists.—Prof. W. J. Beal, Agricultural College; Prof. F. C. Newcombe, Ann Arbor.
Zoologists.—Prof. W. B. Barrows, Agricultural College; Prof. J. Reighard, Ann Arbor.

CONTENTS.

Page.

Finances.... 7

Publications.... 7

Work ready for publication.... 8

Co-operation.... 9

Work of the year.... 10

Legislative matters.... 11

Recommendations.... 12

Topographic survey.... 12

Constitutional changes.... 13

Peat.... 15

Coal.... 15

Limestone.... 18

Cement and lime.... 19

  Some conditions influencing constancy of volume in Portland cement, by E. D. Campbell and A. H. White.... 20

  Calcination of lime and clay mixture to make Portland cement, by F. J. Beal.... 22

ANNUAL REPORT, 1907.

To the Honorable the Board of Geological Survey of the State of Michigan:

Gov. Fred M. Warner, President.
Hon. D. M. Ferry, Jr., Vice-President.
Hon. L. L. Wright, Secretary.

Gentlemen:—I beg to present herewith this my ninth report for the fiscal year from July 1, 1906, to June 30, 1907, inclusive, and for the field season of 1907.

FINANCES.

The following is the usual statement of expenditures from the annual appropriation:

	Salary.	Field.	Office.	Total.
July	$589.03	$155.96	$19.49	$764.48
August	601.00	163.31	33.55	797.86
September	503.00	124.08	121.57	748.65
October	397.63	62.82	36.03	496.48
November	424.00	103.11	56.37	583.48
December	427.19	12.61	31.37	471.17
January	392.20	92.18	50.68	535.06
February	400.60	54.16	65.51	520.27
March	392.20	2.82	15.85	410.87
April	477.46	188.02	30.21	695.69
May	430.40	47.99	128.67	607.06
June	873.12	183.26	268.62	1,325.00
Total	$5,907.83	$1,190.32	$857.92	$7,956.07

In addition to this we had:

For the year 1906–7, to be used in the topographic survey through the U. S. Geological Survey, $3,000.

Of this there was expended in completing the survey of the Rochester and Pontiac quadrangles, $2,991.09.

The legislature of 1907 have granted an additional $3,000.00 for 1907–8, which is being expended on the Milford and Howell quadrangles, and $500 on a survey of Calumet, a work of especial importance to the College of Mines in their gravity determinations. This as well as the appropriation for biological survey is provided by Act 245, Session 1907.

PUBLICATIONS.

On the new system practically the sole publication of the Board is its annual report. The report for 1906 which should be out in November, 1907, will therefore be a book of 601 pages, with very numerous maps and plates. Besides my personal report it contains a report of the late Prof. Russell's survey of a portion of Menominee, Iron, and Dickinson Counties. This is mainly on the surface geology, and contains an especial description of the drumlins so characteristic of this region.

From Prof. C. A. Davis comes a report on peat, which I believe to be of value to science and the State.

A section across the Copper Range at the west end of the State, from Bessemer north, by W. C. Gordon and myself, will prove of service when commercial exploration strikes this hitherto neglected part of the State.

A paper by Prof. C. S. Sargent on the Crataegus—hawthorn or thornapple—was heartily recommended by the Botanists on the Board of Scientific Advisers, and is a detailed account of the species of this genus in which Michigan is so wonderfully rich that the discrimination has been very hard for our local collectors. It is hoped that it will add to our knowledge of the origin of the plant species as well as aid our local teachers and botanists.

Papers have also appeared in "Economic Geology," the "Michigan Miner," Transactions of the Lake Superior Mining Institute, Proceedings Michigan Academy of Science, Bulletin Geological Society of America, and Journal of Geology.*

WORK READY FOR PUBLICATION.

In the report of the Board for 1907 should be included, besides my report, at least the following:

1. A report by Prof. H. Ries on molding sands and on some tests of fire resistance, for engineers.
2. A report of T. L. Hankinson and others on the plants and animals of Walnut Lake, with especial reference to occurrence of whitefish therein, for zoologists, botanists and teachers.
3. A description of the geology of the copper bearing rocks; for people generally, and for teachers, by myself.
4. A description of the deeper mine waters which are strong brines, by Dr. Fernekes and myself; for mining men, chemists and geologists.
5. Four sheets out of a map of the surface geology of the State to be covered by nine sheets, these four covering the surface geology of the Lower Peninsula; not only for geologists, but for all those interested in the agriculture, the soil, the clays, sands, etc., of the State.

It is quite likely also, if the date of transmission to the printer is delayed that we can include a number of other reports.

Among these are Davis' on Tuscola county, Gregory's on Arenac county, Meuche's on the Development of Mining Machinery and the Geological Factors Therein, and further contributions by myself to a knowledge of the copper bearing rocks and the distribution of the lodes therein, including several detailed cross sections and maps. With this Dr. Wright's report on Mt. Bohemia could profitably be included.

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*"Salt Water in Lake Mines" and "Geology of Keweenaw Point," Lake Superior Mining Institute, Vol. XII, 1907, pp. 81–104, 154–163.

"Prospects for Oil and Gas," Michigan Miner, March and April, 1907.

"Dr. Carl Ludwig Rominger," Michigan Miner, June, 1907.

"The Formation of Lake Superior Copper," Science, April 12, 1907, page 589.

"The Early Surroundings of Life," Science, August 2, 1907, p. 129.

"Chemical Evolution of the Ocean," Bulletin Geological Society of America, Volume XVII, p. 691.

Discussion of Howe's piping and segregation of steel ingots, Trans. A. I. M. E., 1907, pp. 765–768.

Notes on the geological section of Michigan, Part I, the Pre-Ordovician, by A. C. Lane and A. E. Seaman, Jour. of Geology, 1907, pp. 680–695.

Contribution to symposium on water supplies, 8th report Michigan Academy of Science, p. 127.

Michigan Topographic Surveys, by W. F. Cooper, Michigan Engineer, 1907, p. 113.

Geology and Physical Geography of Michigan, by W. F. Cooper, Michigan Academy of Science, ninth annual report, 136.

Some interesting glacial phenomena in the Marquette region, Chas. A. Davis, Michigan Academy of Science, ninth report, p. 132.

I should like also in the near future to give a really popular account of the geology of the State, for teachers and those with no special knowledge of geology, saying also something about the prospects for oil and gas.

CO-OPERATION.

We have continued our policy of general co-operation with all agencies or individuals who are studying the resources of the State.

It seems to be worth while to list some of these that those interested may look up the matter.

The U. S. Department of Agriculture, under Milton Whitney of the soil division have now made soil survey of Allegan† (1901), Owosso (1904), Pontiac (1904), Alma (1904), Saginaw (1904), Munising (1905), Oxford (1905), and Cass (1906). Moreover, they have, at my requests, sent us maps marked with locations for gravel pits and notes on road materials. I append the letter on the area issued since last year.

Bellefonte, Pa., Sept. 23, 1907.

Prof. Milton Whitney,
Chief of Bureau,
Washington, D. C.

Dear Sir:—Your letter of the 19th inst. regarding the location of gravel in the Cass county, Michigan, area, has been received. I have gone over the soil map and have indicated with a red cross the areas which I recall where gravel beds containing suitable road building material can be found. Gravel pits have not been opened in all these areas, but the surface features, the presence of a high percentage of gravel in both soil and subsoil, and the fact that a gravel bed is encountered at a depth of three feet in most of the places, indicates that gravel deposits exist.

All of the soils of the Cass county area contain varying amounts of gravel, and beds have been found in every type except muck, clyde and meadow. The soil mapped as Miami gravelly sandy loam contains a higher percentage of gravel than any other type, and the greater proportion of the gravel beds are found in this soil. Miami loam, sandy loam, and sand also contain a few gravel pits where material suitable for road building may be obtained. These gravel deposits usually occur as low hills or knolls and the gravel is encountered at from 3 to 5 feet below the surface.

Very respectfully,
(Signed) W. J. GEIB.

With the State Highway Department, whose headquarters are located just across the hall from us, relations have been more informal, but very pleasant.

The U. S. Geological Survey, topographic division, has in co-operation finished the field work of the Howell sheet and begun in the Milford and Calumet Special. The work was in charge of Mr. A. M. Walker.

Professor W. H. Hobbs, assisted by C. W. Hunt, were employed about Green Bay in making accurate lines of levels of some of the old shore lines. Prof. W. M. Gregory did similar work from East Tawas north. This work was undertaken by request, to further an elaborate report of the U. S. Geological Survey by Messrs. Frank Leverett and F. B. Taylor upon the geological history of Michigan during the time of the retreat of that ice sheet which once covered all this part of North America, and was the main factor in the present soil distribution. It is in continuation especially of Goldthwait's work in Wisconsin. The old shore lines appear, rise and fan out to the north. In producing this effect three factors were perhaps concerned —the *direct attraction* of the ice, the compressing effect of the ice on the rocks beneath, and a tendency to sink the solid crust down into a more or less fluid layer beneath as a boat would be loaded. How far these factors really entered into the result is a question of great interest to the geologist. Whether the relative uplift of the land is still going on or not, and whether it is a tilting or bending or a blockwise uplift has some practical importance.

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†Field operations of the Bureau of Soils of the year given in parentheses.

From the U. S. Survey we have also obtained the assistance of Dr. Geo. H. Girty, who is to work over the Carboniferous fauna, and Mr. A. J. Hazelwood of the U. S. Geological Survey, assisted by your Mr. W. F. Cooper, have examined some coal mines as suggested by me, with the object of seeing how much fuel value is now wasted.

The new Director of the U. S. Geological Survey, Dr. G. O. Smith, invited the officers in charge of the various State Geological Surveys to meet him in Washington with a view to more harmonious work. There was a good attendance, and such meetings will in all probability tend to remove any friction or occasional waste of money that may have occurred in the past. In connection therewith there was a meeting of the State Geologists of the Mississippi Valley.

Assistance has also been obtained from the College of Mines and the Agricultural College. The chemical assistance of Dr. Fernekes, Mr. Wilson and Prof. Kedzie in the study of brines has been especially appreciated.

It will be noted that our special assistants are well scattered through our various State Institutions. It is the policy which has seemed wisest that your Board should along the lines of research which the legislature has put in its charge be a uniting bond among those interested.

WORK OF THE YEAR.

The State Geologist besides his multifarious executive, editorial and consultive duties (for almost every mail brings questions to answer and samples to examine), has spent most of his time on the copper bearing rocks and the occurrence of brines therein,* and in the southern part of the State.

Mr. Harry R. Wight has had charge of the correspondence, the sale and distribution of reports, and has assisted in blue printing and in many other ways.

During the calendar year of 1907 Mr. W. F. Cooper has been largely engaged in editorial work on the annual report for 1906. In the field he did some work for the State Highway Commission on the limestone formations near Jackson, and during a leave of absence without pay, studied shale and limestone near Saginaw Bay. He also assisted Prof. Sherzer in Wayne county and on the salt shaft, and Mr. A. J. Hazelwood of the U. S. Geological Survey who came to study coal waste. Some time has been spent in running levels and compiled data for a topographic map of Saginaw county. He has also articles in a report of the Michigan Academy of Science and Michigan Engineering Society.

Mr. A. H. Meuche has had charge of the Houghton office, and besides his report on the Development of Machinery in its geological relations, has done much work on copper country maps and has had charge of the party surveying and compiling a map of the Ontonagon copper mining district.

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*See list above.

Of those employed for a time or on contract, the following report may be made:

Prof. W. H. Sherzer has kept track of the developments at the salt shaft and has also been at work on his Wayne county report.

Prof. C. A. Davis has edited the peat report and reviewed all and contributed certain parts to the Walnut Lake report. He has been interrupted by peat work for the U. S. Government, but is now finishing his Tuscola county report.

Dr. C. H. Kauffmann has continued his studies of the mushrooms in an unusually favorable season.

Prof. Mark S. W. Jefferson made some studies of stream erosion, coming to the tentative conclusion that they tend to cut their south banks more as the land tilting is still going on.

Dr. F. E. Wright spent a couple of months in the Houghton office finishing his Mt. Bohemia report.

Prof. A. W. Grabau has continued his work on the Traverse group and also assisted in correlating the beds of the Oakwood salt shaft.

Prof. W. M. Gregory has continued his work on his Arenac county report.

LEGISLATIVE MATTERS.

With your consent I asked the legislature for the following sums:

BUILDING.

Cases (250)	$250 00
Cement walks	60 00
Wiring (25x2)	100 00
Veneer (550–1050)	700 00
Furnace (360)	300 00
Addition to lot	750 00

ADDITION TO BUILDING.

60x34x22 ½x10	4,500 00
Stacks, 3 stories @ $1,700	5,100 00
	$11,850 00

BIOLOGICAL SURVEY.

Fish Work—	
Biologist	$1,200 00
Assistant	200 00
Fisherman	500 00
Chemist	600 00
Equipment and Expenses	500 00
Educational report, on one area	500 00
Algae report	500 00
Bradford, Bay county	100 00
	$4,100 00

TOPOGRAPHIC SURVEY.

($1500–$2500 each) x (4–6 sheets)	$10,000 00

The committee on Geological survey who visited the building we now occupy in Houghton and saw the situation concluded that the old building was a disgrace to the State (in which they are not without some justification) struck out the provision for repairs and addition, and instead inserted one for a new building. Then in the last days of the session the Ways and Means committee who had not, so far as I know, been near the Houghton or Lansing office of the Survey, cut out the provision for the new building, and very naturally in the rush, didn't reinstate any of the items for repair and enlargement of the present building, which naturally in two years will look worse than ever. It would seem as though the State could afford a sidewalk in front of its property.

RECOMMENDATIONS.

However, there is this consolation. As near as I can find out a suitable new and fire proof building would cost much more than was suggested. There is no doubt that our work is more and more hindered, more cramped, and less effective than it might be and should be owing to limited quarters for collections. Not only that, but is going to be more and more so in the future. Investigation and mining tends to show a greater permanence of copper enrichment at certain horizons, and calls for a sharper and closer determination of beds from year to year.

To this end samples of the various borings and beds should be preserved. The diamond drill core sections are being made at a cost of from $3.00 to $5.00 a foot bored, and the cost per foot of core saved it is safe to put near $5.00 a foot. There are many thousand feet now preserved in our office, and tens of thousands of feet one might almost say without exaggeration are scattered along the range in buildings not fire proof, and in many cases mere shacks, in wooden, mouldering boxes. This material is of value not only for the local goelogist and miner, but for the solution of many broad scientific problems.

We could have it,—at least a great deal of it, were we in a position to give it proper fire proof storage.

It would be a graceful and gracious monument of foresight and far sight if some one so placed as to appreciate the value of these records, should erect a dignified building for their keeping—a stone library for a library of stone. But I think the State itself, which derives a revenue from every successful exploration, whose wealth is curtailed by every unwisely directed, fruitless or bootless exploration, can afford a plain but substantial building for them, to the end that money spent in exploration may be put to the best possible advantage, and the great fabric of organized Science which has added so much to the welfare of mankind derive the benefit of this expensive work. I may say that without the study of such drill cores I should probably never have arrived at my theory of the dependence of the grain of igneous rocks upon the distance from the margin, which has proved of distinct economic as well as scientific value.

I believe there can be wisely expended on such a building at Houghton, $20,000.00.

TOPOGRAPHIC SURVEY.

I hesitate to urge you to ask for farther appropriations for joint topographic survey until such time as the legislature feels that the State can afford to grant sums large enough to work with economy, to make the necessary supervision not burdensome, out of proportion, and be comparable with those granted by other States of like rank. Ohio has been granting $20,000.00 per annum, and Illinois $10,000.00 per annum.

If Michigan, which, as the late Senator McMillan said, more than almost any other State needs just such maps, with all her water power resources, lands to drain, electric roads to run and other engineering projects which would be aided or suggested by such maps, beside the use of them geologically and by teachers, can not expend at least $10,000.00 within a biennial period, which with an equal amount put in by the gen ral government would make $20,000.00, it would be well—I believe I am in agreement with the authorities of the U. S. Geological Survey in saying—not to put in anything at all.

The demands from the several states for co-operation from the general government are so numerous that I have known of refusal of co-operation when the legislature had already made the necessary appropriation.

The endorsements of these maps by the Academy of Science, Engineering Societies and others I need not repeat.

The Biological Survey could in my judgment expend with profit $2,500.00 per year.

I have received much assistance by letter from time to time from the various gentlemen composing the Board of Scientific Advisers. At their fall meeting, held Nov. 14, the following resolutions were passed:

Paleontologic material should be returned to the Board of Geological Survey as soon as the report is published, unless permission for further detention is given by the State Geologist.

It is recommended that so far as the expenditure of the funds of the Biological Survey is concerned that the balance, not otherwise appropriated, be referred to Prof. Reighard and Mr. Lane.

Realizing the importance of reforestration to the interests of this State, we recommend that the State Geologist or Board of Geological Survey consult with the Forestry Commission and the Professors of Forestry at the University and Agricultural College with the object of furnishing all assistance that the Geological Survey might properly give in the work of reforestration.

We recommend that the Board see what can be done in connection with the Forestry Commission toward publishing a book of a popular nature on the condition and prospects of Michigan forests, using the maps already prepared by Prof. Davis.

Voted that the matter of Bradford and Brown report be referred to Prof. Newcombe.

CONSTITUTIONAL CHANGES.

May I be permitted with all deference at this time to urge upon the Board certain constitutional changes.

In connection with the work of this board it has been impossible not to note the devastation of the forests, and the impoverishment thereby of the country, especially in connection with fires. Studies under this Board have shown that there is a slow improvement of the forest soil and that as under the shade of the forest leaves and humus accumulates, jackpine may be replaced by white pine and that in turn by hardwood. Once a forest is devastated and fire gets in not only the trees but the soil itself, the accumulation of a geological cycle, is burned away and the surface may at times revert to shifting dune sand. Rapid erosion, heavy loads to the rivers, upgrading of their beds, sharp and disastrous floods in the spring, severe droughts and very low run off and feeble water power in the summer, all then may in some way be connected with the reckless stripping of the once supposed "inexhaustible supplies" of timber. These, then, are geological consequences of the first order. So it does not seem out of your or my province to urge that from the constitution should be eliminated any clauses that might interfere with stumpage taxes or other means of relieving private forest culture of present unfair burdens. Nor should there be anything to prevent the State itself from going into forest culture or such other plans of internal improvement and development as may become and be deemed wise by succeeding legislatures. For as the commonwealth becomes more and more closely settled the regulation of our rivers, the inflow of sewage into them and the outflow of drains from lowlands, and their floods, must become more and more a matter of State concern in order to conserve our State resources and secure the greatest good to the greatest number.

It is my belief too, that Prof. Roth is entirely right in saying that every acre of its land is worth at least $5.00 an acre to the State of Michigan.

But if the State is to remain owner in any large degree of its lands, it should be able to lease them to cut timber and to explore for mineral wealth.

In fact as regards the whole matter of exploring for oil and gas in my judgment it could be very much better controlled, with less waste of money and less danger of falling into the hands of the monopolies too powerful to control if, as I have elsewhere suggested, the following policy were adopted.

Let the State exercise its right of eminent domain as to petroleum, as it has according to the fundamental law in gold and silver, and arrange terms by which the development of the same in suitable areas and under suitable restrictions, and with such provisions for the protection of the public as the people of the State, through their legislatures, might seem wise, should be given to those who choose to run the risk so that they may reap the rewards, if any. For instance, provision might be made that any company having actual capital paid in and available as an exploration fund enough under ordinary circumstances to put down say a dozen wells to some horizon known to yield some oil or gas, should have exclusive right to the oil or gas in a given county or district for a term of years or so long as they continue exploration or production, subject (1st) to the usual royalties to be paid to the county authorities, which, if they exceed the county tax should be divided pro rata among the land owners; (2nd) to the usual provisions of oil leases as to making good surface damages, and (3rd) specific tax, and in case two equally responsible companies were bidding for the same county that offering the largest specific tax might be preferred; (4th) in case a monopoly detrimental to the public welfare were threatened, the State might step in and buy out the company at a fair price.

I do not say that this plan should be introduced into the constitution, although I am convinced that this would be a far better plan than the present. But ought not the constitution to leave opportunity for the legislature to provide for this or some similar plan? Can anything be much worse than the waste and scrabble, stock jobbing and loss of about half of the material of the Spindletop furore? And on the other hand, is control by a monopoly of the type of the Standard Oil in all ways acceptable?

In accordance with my custom heretofore I will append gleanings from our work for the year of matters not large enough for a separate report but of some immediate interest.

PEAT.

To the elaborate report on peat of last year we have a few words to add. Prof. C. A. Davis, author of that report, has been extending his researches over the United States, under the auspices of the U. S. Government, and in connection with the Jamestown Exposition had quite an exhibit. There was in October at that exposition quite a congress of those interested in the exploration of peat.

Just at present, however, other uses for peat than for fuel are interesting.

The more fibrous peats make good paper, and the Pilgrim Paper Co., at Capac, making paper for cartons, boxes for tacks, etc., is understood to have its output entirely engaged.

This is one of the built up bogs, due perhaps to the successive elevation of beaver dams, and for such use too great decomposition is not desirable.

A paving block has been made in New Jersey by the Pompton Peat Fuel Co. of the more decomposed, ground up and compressed peat. It should not be forgotten that once dried, peat becomes insoluble.

But the most interesting use is as fertilizer filler—as an absorbent of stock yard and slaughter-house waste. This use bids fair to have a wide application. Not only does the great absorbent and antiseptic power of the peat enable the fertilizer to be put on the market from four to six weeks sooner than otherwise (a sample with 83 per cent may appear dry), but its own composition adds material of value, humus, and carbon and nitrogen. Just how much this is worth to the farmer, and in particular just how far the nitrogen, which may run up to 3 per cent in a dry feeling peat holding 83 per cent water, is in a form that is worth paying for is a point upon which the Agricultural College experimenters are at work. It is difficult to distinguish by analysis the nitrogen from cottonseed meal, hoof meal, tankage, etc., from that of peat. No doubt they will also try if some bacterial fermentation to make it more available can not be devised. Freezing and thawing is said to make the nitrogen more available. In time, no doubt, with the approaching exhaustion of our timber resources, the manufacture of peat, coke and fuel gas will be commercially realized here as abroad. It would esem also that concerns using marl for cement could well consider utilizing the peat which so often overlies it in one of the several ways mentioned.

COAL.

Prof. S. W. Parr, inventor of the most useful calorimeter, has been working up the heating power of Illinois coals[‡] and discussing the classification of coals.[**] About the only other tests he used were those of the St. Louis testing plants, those of Lord and Haas, and those made for us by H. J. Williams, who has recently prepared specifications for coal for the city of Boston. From total carbon Parr subtracts "fc" the "fixed carbon" left in the coal and finds the ratio of this "vc" to the total carbon

$$\frac{c - fc}{c} = 1 - \frac{fc}{c}.$$

In my work in Volume VIII, I classed the seams by the ratio of fixed carbon to the total combustible, or fixed carbon and volatile combustible of a proximate analysis. The total carbon is relatively easy to obtain with the Parr calorimeter, being absorbed as CO_2 by the sodium peroxide, and so he proposes as a basis of grading replacing the total combustible of the proximate analysis by the total carbon. This has the very great advantage of getting rid of the troublesome question how the line is to be drawn between moisture, combined water, and volatile combustible. It is, however, probable that in making perfect combustion and in making fuel gas, the water can not be so simply eliminated, and its heat of combination with the sodium peroxide must also be accounted for.

[‡] Bulletin No. 3, Illinois State Geological Society.

[**] Campbell, E. R., and Fraser, Prof., have written also in Trans. and Bulletins in Am. Inst. M. E., 1906, 36, on the grading of coal. See also Grout, F. F., Economic Geology, II, p. 225.

It seems worth while, nevertheless, to reproduce his results on Michigan coal, adding to the samples he worked up, one analyzed by Dr. Koenig, given in the Annual for 1905, and an analysis of a coal by Prof. Kedzie which Mr. Cooper thinks represents the Upper Rider above the Upper Verne, a seam not hitherto analyzed. This sample, No. 14, was of churn drillings from a hole put down by T. Archambeau on the farm of P. Brissette, 497 feet N. of S. line fence, N. E. ¼ of N. W. ¼ of Section 14, Kawkawlin Twp. 15 N., R. 4 E. The record was as follows:

Sandy Clay	66'	66'	
Gray Shale	9'	75'	
Gray Sand Rock	17'	92'	
Dark Sand Rock	2'	94'	
Gray Sand Rock	5'	99'	
Gray Shale	5' 6"	104' 6"	
Black Slate	11"	105' 8"	
Coal—Upper Rider	3' 6"	108' 11"	478 A. T.
Black Chip Slate	7"	109' 6"	
Gray Shale	6"	110'	

This being a new seam it seemed worth while to have it analyzed. The result of Prof. Kedzie is as follows:

"Coal Sample 'P. Brissette—40 acres—test hole No. 14.' All results on thoroughly dried sample.

Proximate analysis—

Volatile Matter	45.02%	
Fixed Carbon	45.50	
Ash	9.48	B. T. U. 13,838 (Parr)

Total Sulphur, 4.19%

Ultimate analysis—

Carbon	69.02%
Hydrogen	7.53
Nitrogen	1.36
Sulphur (Volatile)	4.12
Ash	9.48
Oxygen (by diff.)	8.57

The ash I find contains—

Fe_2O_3	3.17%	Calculated to the original coal.
S	.068	

(Signed) FRANK S. KEDZIE."

We give Prof. Parr's proposed classification of coals below. The Saginaw seam belongs sharply to class. B, of the bituminous coals, while the upper seams, the Verne coals and Upper Rider belong to class D, toward the lignitic end. They have perhaps never been buried very deep, and are distinctly nearer the wood end of the series.

TABLE A—PARR'S OUTLINE FOR CLASSIFICATION OF COALS.

Coals	Anthracite	Anthracites Proper		Ratio $\frac{vc}{c}$ below 4.
		Semi-Anthracite.		Ratio $\frac{vc}{c}$ between 4 per cent and 8 per cent.
		Semi-Bituminous		Ratio $\frac{vc}{c}$ from 10 per cent to 15 per cent.
	Bituminous	Bituminous Proper	A	Ratio $\frac{vc}{c}$ from 20 per cent to 32 per cent. Inert volatile from 5 per cent to 10 per cent.
			B	Ratio $\frac{vc}{c}$ from 20 per cent to 27 per cent. Inert volatile from 10 per cent to 16 per cent.
			C	Ratio $\frac{vc}{c}$ from 32 per cent to 44 per cent. Inert volatile from 5 per cent to 10 per cent.
			D	Ratio $\frac{vc}{c}$ from 27 per cent to 44 per cent. Inert volatile from 10 per cent to 16 per cent.
		Black Lignites		Ratio $\frac{vc}{c}$ from 27 per cent up. Inert volatile from 16 per cent to 20 per cent.
		Brown Lignites		Ratio $\frac{vc}{c}$ from 27 per cent up. Inert volatile from 20 per cent to 30 per cent.

TABLE B—ANALYSES BY H. T. WILLIAMS AND OTHERS.

Description.	Proximate Analysis.				Additional Factors.			Deduced Values.			Hydrogen Values.	
	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur	Total Carbon.	Volatile Carbon.	Hydrogen from curve.	Ratio vc/c	Inert volatile pure coal basis.	H. from ultimate analysis.	H. from indicated calories.
1. P. M. No. 1, Saginaw Seam........	10.15	33.14	53.95	2.76	1.10	71.11	17.16	3.91	24.13	12.60	3.64	3.74
2. Standard, Saginaw Seam............	10.67	33.59	53.80	1.94	1.04	71.67	17.87	3.91	24.93	12.36	3.84	3.67
3. Somers, St. Charles Seam..........	7.79	34.74	52.58	4.89	1.01	71.37	18.79	3.87	26.33	12.67	3.33	3.88
4. Owosso Seam?......................	7.58	35.70	52.69	3.76	1.50	72.88	19.92	3.94	27.33	11.66	3.81	3.80
5. New Hope, Jackson Verne Seams, One of..........................	5.58	46.73	45.28	2.41	2.83	73.55	28.27	4.38	38.43	12.22	4.72	4.45
6. New Hope, Jackson Verne Seams, One of..........................	5.93	46.59	44.64	2.84	3.07	72.42	27.78	4.33	38.36	12.56	4.67	4.59
7. Wenona, Bay Co., Lower Verne.....	8.71	38 45	41 16	11 68	2.72	65.87	24.71	4.25	37.51	8.50	4.24	4.01
8. Albee Township, Saginaw County....	5.82	39.79	45.15	9.24	3.83	68.33	23.18	4.22	33.92	10.19	4.17	4.46
9. Sebewaing, Verne Seams, One of....	6.09	39.54	46.06	8.26	5.72	68.07	22.01	4.14	32.34	9.40	4.62	4.17
10. Michigan, Bay County.............	5.01	39.62	41.67	13.70	6.66	62.29	20.62	3.79	33.10	10.51	3.77	4.32
11. Central, Bay Co., Lower Verne......	4.52	40.57	42.16	12.75	6.92	63.57	21.41	3.90	33.68	10.08	3.99	4.15
12. Wenona, Bay Co., Upper Verne.....	3.78	41.18	49.34	5.70	2.50	73.09	23.75	4.44	32.49	11.58	3.90	4.51
13. Wenona, Bay Co., G. A. K. Verne..	1.09	42.11	50.89	5.91	1.95	72.74	21.85	5.40	30.00	14.60	3.74	....
14. Bressette, F. S. K., Upper Rider....	Dried Drillings	45.02	45.50	9.48	4.12	69.02	23.52	3.88	34.10	15.10	6.51	14.70

For further information regarding analysis 1 to 13, see Vol. VIII, Part II, pp. 89, Et seq.

The following note refers to specimens at a depth of about 175 feet from the present surface from room 23, entry 4, west, of the south part of Wolverine Coal Mine shaft No. 3. This I take to be the top of the Verne seams. The roof was a beautiful display of bark and fern and rush leaves. The foot is mainly a smooth looking hard white shale. There are in a sense four seams of the coal in 80 inches, but the lower two are very close together. There comes between them a sulphurous seam, three inches to two feet thick, with many pieces that look like wood chip pebbles, with impressions of Lepidodendron bark in pyrite.

Washington, D. C., Nov. 30, 1907.

Dr. A. C. Lane,
State Geologist,
Lansing, Michigan.

Dear Doctor Lane:—The specimens of shale sent by Mr. Thompson from the Wolverine Mine No. 3, at Bay City, Michigan, contain excellent impressions of a very early form of *Lepidodendron aculeatum,* this is, in some respects, intermediate to *Lepidodendron obovatum;* several cones, included in the rather ill-defined species *Lepidostrobus variabilis;* a considerable number of fern fragments which, in spite of their differences in aspect, evidently belong to a single plant. This fern is very interesting since it almost certainly represents a new form, if not an entirely new species, belonging to the peculiar group typified by *Neuropteris desorii.* The plant should be duly described and figured.

The associated forms mentioned above have no other effect on our correlations of the Michigan coals than to confirm a reference of this bed as probably near the top of the Pottsville. None of the material sent by yourself or your colleagues, from the Michigan coal fields appears to furnish any evidence for an age earlier than the Upper Pottsville.

The University Museum at Ann Arbor contains a number of typical examples of the Upper Pottsville phase of *Lepidodendron clypeatum,* from Jackson, Michigan. I presume it older than the coal at Bay City. * * * I remain,

Very truly yours,
(Signed) David White.

The general trend of core drilling and development this year has been west from Bay county into Midland around Edenville and Gladwin, and east into Tuscola, where a mine has been opened up near Unionville. I suspect considerable faulting and disturbance will be found in this latter region. The exploration for coal near the corner of Missaukee, Wexford and Osceola counties has not reached bed rock or coal but has been in surface deposits still at 400 feet. The map of the State printed in U. S. Water Supply Papers Nos. 182 and 183 and issued herewith would indicate over 600 feet of drift in this region. Coal has been found so frequently and in such large pebbles in the drift of the southern part of Roscommon county, that it is probable that a coal seam outcrops under a heavy covering of surface drift near the south line of this county. Coal has also been struck in wells for water a little north of Lansing. A coal washery at Saginaw shows progress in economy, but I hope Hazlewood's work may lead further in that direction and especially to the use of the black shale or bone coal, with ash over 20 per cent, but a large amount of volatile hydrocarbon. Of this there is a good deal, which would not bear much transportation but might be utilized for fuel or gas at the plant. It will often have half the heating value of coal, but can not of course be mined at the same rate.

LIMESTONE.

Descriptions of the limestone resources of the State have been given in the annual for 1901, especially pages 139 to 210; for 1902, pages 17 to 19; for 1903, pages 171 to 174; for 1904, pages 122 to 124; and for 1905, pages 563 to 567.

During the past year our attention has been especially called to the Niagara limestones and those around Detroit. Professor Sherzer and Grabau will make a report on the latter in connection with the Wayne county report. But a few notes on the development of limestone in the Niagara may not be out of place, especially as it has been generally understood that the Niagara limestone is dolomitic or magnesian, and might more properly be called dolomite.

The caves which I visited in 1901, on sections 15, 16, 21, and 22, T. 44, R. 7, were revisited in the spring of 1907, and have been opened out into extensive quarries at Chase Osborn. An unusually good chance is offered to study glacial striations in part of the quarry, other parts under a less impervious cover. The striations run to N. 28° W. from S. 28° E., or to N. 40° W. The N. 30° W. and another N. 10° E. are still older. There are chatter marks, minutely faulted, curving convex to the northwest. The striation is somewhat more north of west than the heavy grooving, and the motion was from the southeast.

At one end of the quarry the surface is very heavily corroded, as exposed gypsum beds often are, and this is in patches only, grooved and striated so that the last ice motion from the south only cut a little into a deeply corroded surface. The indications are that the very last motion of the ice in this region was from the Lake Michigan lobe of the Wisconsin ice sheet, spreading from a center in Labrador, and that the direction of ice motion became more northerly toward the end. A peculiar set of slanting joints at right angles occur. Others are more nearly vertical and run with the striæ.

The section of the quarry is as follows:

3 feet—Limestone, with Orthoceras, a loose Favositid, a small gastropod, but most abundant fragments of heads of stromatoporoids.

1 foot—Greenish sandy looking limestone, with greenish tubes running into each other (anastomosing), with corals and stromatoporoids, which latter show well on the green surface.

6 feet—Very massive.

4 feet—Mottled brown and light with Stromatopora heads.[1]

9 feet—Finely banded mud rock (calcilutite) with quite persistent bands of holes, empty gastropod cavities half way down. These have calcite crystals lining them. A Leperditia and stylolitic sutures occur and this lower part has a more porcelanic, less sugary appearance than the upper part containing the coral and stromatoporoid heads. A notable thing is the absence of Pentamerus.

The shape of the exposure may best be illustrated by a sketch.

The shipment of the limestone which (runs up to 98 per cent $CaCO_3$) runs up to 19 to 30 cars a day, two-thirds of it say goes to the Duluth furnaces for flux. But some is used by the Munising Paper Co. in the sulphite fibre process, some to make acetate of lime at Marquette, and some goes to Sault Ste. Marie, for flux, or for paper or carbide manufacture. However the calcium carbide is more produced by another quarry.

A price quoted is: 45c a ton for limestone; 45c a car for screenings.

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[1] Prof. W. A. Parks of the University of Toronto kindly identifies the stromatoporoid as Clathrodictyon vesiculosum, which he has not found high in the Niagara, but commonly in the lower beds and Clinton. Letter Jan. 8, 1908.

Besides the quarry the caves I explored in 1901 show that there is considerable extension of this high grade limestone which seems to be more soluble than the dolomite.

The elevation of the quarry is about 820 A. T. The local dip appears to be a few degrees (5° to 7°) to the east. But really, as we know from deep wells at St. Ignace and Manistique the general dip of the formation is to the south at about 50 feet to the mile.

The carbide works are, however, supplied by another quarry on Section 6, T. 44 N., R. 8 W. This is farther north but it is also nearer the top of a hill, which extends over into Section 31, T. 45 N., R. 8 W., and to an elevation of about 900 feet A. T., and then breaks off suddenly with a northward facing escarpment of limestone above an old sea cliff. About 80 to 100 feet below there is a big spring starting a regular stream, of the kind typical of limestone countries. Again in the N. E. ¼ of the S. W. ¼ of Section 25, T. 45 N., R. 9 E. is another of the streams making a small pond. There is a strong smell of hydrogen sulphide, and a heavy coating of sulphur, and the water has a peculiar greenish tinge and a temperature of about 45. 2° F. This has an elevation of only 777 A. T. Similar streams may be expected, as well as artesian wells, on the north side of the limestone ridge and may be a useful guide.

But to return to the quarry. The section is about as follows:

18 feet—Solid limestones which may be subdivided into

A.—6 feet—With fossil corals, Zaphrentid and favositid forms and gastropods, banded especially at the bottom.

B.—6 feet—Compact, brownish, splintery, etc., also a cystiphylloid coral.

C.—Also massive.

The calcite crystals in the cavities show a prism or long + R with — ½ R termination. Below these 18 feet in which is the main quarry, a large part of which is said to run 98 per cent $CaCO_3$, (not less than 93 per cent being desired for carbide), come layers not so uniformly high, as follows, exposed in a smaller central pit:

D. 2 feet—Thin bedded with green partings.
6 feet—Lime mud rock, calcilutite, with very distinct, nearly horizontal bedding, dip 1 foot in 40 to W.
1 foot—Brownish banded with holes.
2 feet—Pink, massive, faulty, banded.
A greenish stratum forms the bottom layer.

The general character of the two quarries is much the same. The general strike of the formation is toward Drummond Island where at the northeast quarter, in a 100-foot section, below dolomite beds full of Pentamerus, siliceous and with chert, Rominger found layers running 93 per cent to 95 per cent calcium carbonate (Vol. I, Part 3, pp. 35–36) and of similar physical character. This gives a strike of 1 S. to 8 E., or S. 82½ E. Allowing for this and the 80 feet difference in elevation, the quarries would be at the same horizon at a dip of about 40 ft and 50 ft to the mile. A dip of about 50 feet to the mile is quite widely indicated for the Niagara.

CEMENT AND LIME.

In the Portland cement industry the tendency to use limestone and the dry process rather than bog lime and the wet process continues.

Dr. F. E. Wright, formerly of this Survey, has with other friends shown that there is no such thing as tricalcium silicate, and what has been so called is a mixture of oxide and dicalcium silicate,†† (the latter 35 per cent SiO_2, 65 per cent CaO).

The statements regarding tricalcium silicate in our report on marl[‡‡] must be modified. How far cements with lime above this ratio need seasoning remains to be tested. The earlier work by the Newberrys was very different in its conclusions, but most cements run not over 60 per cent CaO. Professors E. D. Campbell and A. H. White, of the University, have been making some elaborate tests on this point and on the ill effects of free magnesia, and we quote the following results of their investigation, of use both to users and manufacturers of cement and also add an interesting paper by F. J. Beal, one of the recent graduates of the Agricultural College, showing the exact changes that go on in burning cement.

SOME CONDITIONS INFLUENCING CONSTANCY OF VOLUME IN PORTLAND CEMENTS

From the article by E. D. Campbell and A. H. White in the Journal of the American Chemical Society, Volume XXVIII, No. 10, October, 1906.

Free lime in Portland cement will not only not be slaked during the mixing and setting of the cement but will not become completely hydrated even when the cement is immersed in water, until about fourteen days have elapsed. The result of this gradual slaking is to produce abnormal expansion of the cement. Any evil effects due to the presence of free lime in cements kept under water will be manifested within two months. In case free lime is present in cement used in structures above ground or where it is usually dry, the expansion due to hydration of the cement will be more gradual but several times greater in volume than when the material is under water. The expansion due to free lime slaking in the air may become so great after a few months as to cause complete disintegration.

The deleterious effects of free lime may be completely removed by aging the ground cement or storing the clinker to weather until the pat will stand a perfect boiling test. Weathering the clinker for three months is usually sufficient. It is difficult to state the length of time necessary to properly age ground cement to eliminate the free lime. It will not ordinarily be less than one month and may be longer according to the conditions under which it is stored.

Cement which passes a perfect boiling test may be safely assumed to contain no free lime. The expansion of a bar of neat cement containing no free lime when kept in cold water for seven days is usually under 0.040 per cent., but occasionally may go as high as 0.060 per cent. A cement with 2.8 per cent free lime showed an expansion of 0.220 per cent in the same period.

The effect of magnesia like that of lime depends less upon its total amount than upon the form in which it exists. Combined magnesia like combined lime has no injurious effect in Portland cement. Magnesia combined with silica and alumina forms a hydraulic cement which is safe but as compared with Portland cement is too weak to be of any commercial value. Free magnesia has no appreciable effect in cement used above ground where it is continuously dry. If the cement is wet for a part or a whole of the time, the free magnesia will very slowly hydrate and cause expansion. Even where the cement is continuously immersed in water the expansion due to free magnesia is not appreciable until after two months and only becomes distinctly evident after a year. The hydration seems to be only well under headway at the time of the first year and expansion continues at an increasingly rapid rate for at least five years, and probably longer. Aging

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[††] Am. Jour Sc., Oct. 1906, p. 284.

[‡‡] Volume VIII, Part 3, page 172.

does not seem to diminish the deleterious effect of free magnesia in cement. This is to be expected, since the rate of hydration of hard-burned magnesia in air is almost imperceptibly slow.

The boiling test for twenty-four hours does not detect free magnesia as it does free lime. Cement containing as high as 4 per cent of free magnesia has passed a perfect boiling test, yet the last measurement of this cement at the end of five years in cold water showed a total expansion of over 1 per cent, nearly half of which occurred during the fifth year after making.

The slow hydration of free magnesia with its accompanying expansion seems to be the probable cause of the expansion, frequently accompanied by more or less complete disintegration, so often noticed in sidewalks, occurring several years after the walk has been laid.

One per cent or less of free magnesia in cements kept under water causes little noticeable expansion even in neat cement; probably simply filling up the voids. Increased percentages of free magnesia cause cumulatively greater expansion until with 3 per cent of *free* magnesia the expansion is too great to be at all safe.

In the manufacture of cement from raw materials containing magnesium carbonate, some portions of the magnesia will remain in the free state. The amount will increase in coarseness of raw materials, increasing percentage of lime and increasing percentage of magnesia. If the total of magnesia does not exceed 3 per cent it is not likely that well made cement will carry enough of this magnesia in the free form to cause injurious expansion in large monolithic structures kept continuously or frequently wet. In structures where suitable provision can be made for expansion joints, a higher percentage of total magnesia is permissible than in monolithic structures. Magnesia should not exceed 5 per cent total when used even under these circumstances.

An increasingly large amount of cement is being used in the structure of buildings where it will never be exposed to the action of water. There is no ground for believing that magnesia even in free form would cause trouble under such circumstances. Free lime, however, is more dangerous in these structures than where the concrete is to be kept damp, because the expanding lime increases its volume much more in air than in water. Concrete made from sound cement will normally contract in the air, and this contraction continues according to our measurements for at least five years and amounts with neat cement to about four-tenths per cent. Whether this contraction will be sufficient to seriously weaken structures such as floors deserves investigation.

Any cement worked up fresh will change its volume more than if properly aged. It will show a noticeable drop in the curve representing change of volume after about three months, a period which corresponds to that in which briquettes show a falling off in tensile strength. Cement should always be aged for work where constancy of volume is of the highest importance. The only disadvantage of aging lies in the tendency for a cement to become very quick setting. If it is aged long enough it reverts again to a slow setting cement.

CALCINATION OF LIME AND CLAY MIXTURES TO MAKE PORTLAND CEMENT.

By F. J. Beal, Engineering Chemist with the Wyandotte Portland Cement Co., of Wyandotte, and the Huron Portland Cement Co., of Alpena.

As is generally known, Portland cement is manufactured from an intimate mixture of lime and clay. The lime may be in the form of marl, limestone or industrial lime, and the clay may be in the form of clay or shale. Besides these, some mills make cement from what is known as cement rock, which contains both the clay and lime in about the correct proportions. If the cement rock does not contain enough lime or clay, the required amount is added as limestone or shale. These two substances are mixed in proportions dependent upon the exact chemical composition of each and subsequently burned or heated to a state of incipient fusion. This fused substance or clinker has changed the mixture of lime or clay to a chemical compound which when ground to an impalpable powder is Portland cement.

The first step in the manufacture of Portland cement is the proportioning of the raw materials. As stated above, this depends upon the composition of the materials themselves and will be governed to some extent upon the thoroughness with which the subsequent operations, such as grinding and burning, can be done in any particular mill. The finer the raw materials can be ground the easier and more completely they may be fused, thus allowing a greater per cent of the lime in the raw mixture without leaving any lime in a free or uncombined state after the process of fusing. An ideal Portland Cement is one in which there are no uncombined elements. There is a loss in the quality of a cement by having too little lime as well as having too much. The limitations of variation in the mixture of raw materials is generally one per cent in their lime content.

After the process of mixing and grinding, comes the burning process or the one in which the mixture of the two substances containing no cementing qualities and capable of crystalizing into rocklike hardness. I shall try to explain the changes that take place during the process by giving the composition of our raw materials and a description of their treatment up to the time they enter the rotary kiln, together with the results of several experiments that I have personally conducted along this line.

This explanation will deal entirely with the so-called wet process. Our clay is a yellow clay containing from 10 per cent to 25 per cent of moisture varying with the condition of the weather. The following is an average analysis of the dry clay. Loss on ignition 7.05 per cent; silica (SiO_2), 65.38 per cent; iron (Fe_2O_3), 2.63 per cent; alumina (Al_2O_3), 21.37 per cent; lime (Ca), 1.66 per cent; magnesia (MgO), 1.05 per cent; carbon dioxide (CO_2), 2.47 per cent. Our lime is a precipitated carbonate of lime received by us in the form of mud containing about 37 per cent of moisture and fine enough to entirely pass a 200 mesh sieve, and having the following composition after drying: Silica (SiO_2), .40 per cent; iron and alumina (Fe_2O_3), .60 per cent; lime (CaO), 55.10 per cent; magnesia (MgO), .30 per cent; carbon dioxide (CO_2), 43.30 per cent.

Our clay is first passed through a rotary drier 50 feet long by 6 feet in diameter. From this it is conveyed to a drypan where it passes under large iron rollers that grind it to a granular form about the size of coarse sand and fine gravel. From here it is elevated to bins in the mixing room ready to be weighed out and mixed with lime. This lime is received at the mill in side dump cable cars carrying approximately 5,000 pounds of lime mud. These cars stop directly over a large hopper into which the lime mud is dumped and through which it passes directly to a large pug mill. Adjacent to this large hopper and resting on scales is a smaller hopper into which the required amount of clay for one car of lime mud is weighed and at the moment the lime mud is dumped into the pug mill the clay is allowed to run in with it and the two are pugged in this mill until thoroughly mixed.

At this point enough water is added to make the mixture or slurry contain from 40 per cent to 45 per cent of water. This is added simply to facilitate the mixing, grinding and pumping of the slurry. From the pug mill the slurry passes through a tube mill. This mill grinds the slurry fine enough so that 98 per cent will pass through a 200 mesh sieve. From this mill it is pumped to large storage tanks from which it is fed into the rotary kilns to be burned.

These rotary kilns are 100 feet long by 7 feet in diameter and lined with fire brick. These kilns are placed on a slant and rotate causing the slurry to gradually work its way from the upper or feed end of the kiln to the lower or discharge end of the kiln. The heating is accomplished by the burning of a mixture of pulverized coal and air which is blown into the front end of the kiln. A heat of from 2500° to 3000° Fahr. is required to burn cement. The following 35 analyses of cement mixture taken every three feet apart from the interior of one of these kilns together with the explanation will show the changes that take place and the effect that they have on the finished product.

ANALYSIS OF CONTENT MIXTURE TAKEN FROM THE ROTARY CEMENT KILN 100 FEET LONG AND 7 FEET IN DIAMETER, SHOWING THE CHANGES THAT TAKE PLACE DURING THE PROCESS OF BURNING.

Sample No.	Distance in feet feed end of kiln.	SiO_2	Al_2O_3	Fe_2O	CaO	MgO	CO_2	Moisture.
1	0	15.76	5.93	1.69	42.74	1.70	31.47	33.96
2	2	14.68	6.52	1.48	43.17	2.26	31.29	44.33
3	5	15.96	7.36	1.48	42.95	1.06	30.92	33.53
4	8	15.88	5.28	1.06	42.64	1.13	33.76	23.29
5	11	15.60	5.78	1.06	43.27	1.50	31.98	14.08
6	14	14.84	5.72	1.48	43.38	1.42	32.69	12.34
7	17	16.14	8.14	1.48	43.27	1.95	28.31	5.97
8	20	15.96	7.05	1.27	42.95	1.87	30.21	1.20
9	23	15.70	6.81	.85	43.06	1.94	30.19	10.12
10	26	14.56	7.07	1.27	43.70	2.56	30.17	.38
11	29	14.20	6.71	.63	43.16	2.51	32.19	4.06
12	32	16.16	9.57	.85	41.69	1.91	29.32	1.78
13	35	15.90	7.27	1.27	43.70	2.17	29.14	2.23
14	38	15.90	7.61	.85	43.16	2.18	29.84	2.12
15	41	14.74	5.74	1.48	43.38	1.95	32.08	2.48
16	44	15.92	7.71	1.69	43.80	1.91	28.42	1.56
17	47	16.24	6.08	1.06	43.70	1.93	30.38	1.43
18	50	14.90	6.13	1.69	43.38	1.97	30.59	1.36
19	53	17.02	7.13	.63	44.43	2.03	27.38	.31
20	56	16.66	6.96	1.48	44.12	1.75	28.12	.07
21	59	17.70	6.52	1.06	44.54	2.16	27.30	
22	62	21.69	8.59	1.27	44.85	2.35	19.04	
23	65	18.62	7.16	1.48	45.49	2.48	24.17	
24	68	16.14	7.80	1.48	45.80	1.76	26.50	
25	71	18.14	7.17	2.11	50.76	1.64	19.89	
26	74	20.00	8.45	1.69	48.97	1.76	19.00	
27	77	21.44	9.59	1.27	55.83	2.18	9.12	
28	80	23.26	11.33	1.99	58.68	2.37	2.00	
29	83	23.00	8.88	2.32	60.37	2.56	1.48	
30	86	22.66	9.74	1.90	62.48	2.70	.26	
31	89	21.20	8.52	2.32	65.12	2.75		
32	92	22.20	11.41	1.97	61.13	2.43		
33	95	21.42	10.82	1.58	63.54	2.59		
34	98	21.30	10.11	1.37	64.06	2.66		
35	100	21.84	9.93	1.37	63.96	2.45		

Analysis by (Signed) F. J. BEAL, Chemist, 1907.

The table gives the chemical composition of the cement mixtures and their respective locations in the kiln. The mixture of the raw materials is controlled by the per cent of lime it contains. It will be noticed in the table that the amount of lime in the mixture from the time it enters the kiln till it passes through the first half of the kiln or 50 feet, has been practically constant, and any variations that are shown in the composition of the mixture up to this point, excepting the moisture are due to the slight variations in the compositions of the raw materials themselves and not due to any change effected by the process. On the other hand, the use of this half of the kiln is to drive off the moisture from the mixture. This is entirely accomplished while the mixture is passing through the first 56 feet of the kiln. That column of the table giving the per cents of moisture in the mixture at various points in the kiln will require some explanation. Sample No. 2 shows that this sample, which is 2 feet from the feed end of the kiln, contains 44.33 per cent of moisture and represents the amount that the mixture contained at the time it entered the kiln, since the feed pipe extends into the kiln this distance. Sample No. 1 is taken from the extreme feed end of the kiln and is of the moisture or slurry which has backed up in the kiln to this point and partly dried. From this point through the first 17 feet of the process the moisture is gradually and rapidly driven off. Samples No. 8 and 10 respectively are very low, while Sample No. 9, which is between these is much higher. This is explained as follows: Samples 8 and 10 are each taken from mud rings which have formed at these particular places, composed of the slurry which has been partly dried or baked, building up and forming rings about a foot thick entirely around the inside of the kiln. Sample No. 9 is of the slurry which is held in more or less of a quantity between these rings and protected by them from being dried out so rapidly. From Sample No. 10 on the change is carried on till the moisture is entirely driven off by the time the mixture has passed through the first fifty-six feet of the kiln, but not as rapidly as in the first part of the operation.

Up to this point the change has been only a physical one, merely the drying out of the mixture. Next comes the chemical change which really starts while the last traces of moisture are being driven out. This chemical change is first the driving off of the carbon dioxide and takes place while passing through 36 feet of the kiln between the points 53 feet and 89 feet. This operation is gradual and effects a change in the lime, changing it from a combined lime to an uncombined lime. The next change is to cause the free or uncombined lime to unite with the silica, iron and alumina to form a chemical compound. This is accomplished at the time the last traces of carbon dioxide is driven off and immediately thereafter. This chemical union between the lime, iron, alumina and silica causes the material to form into clinker or fused particles about half an inch in diameter or smaller. This clinker when cooled and ground is Portland cement.

The changes that take place in the process of burning are not only shown by the change in chemical composition but also by the change in color. The first eight samples are of a creamy color which is the color of the original slurry or mixture. At Sample No. 9 the color changes to a very light gray or slate color which remains till it got to No. 20, where the carbon dioxide starts to be driven off and the color changes to a very delicate pink. The pink color remains until we reach Sample No. 27, at which point about two-thirds of the carbon dioxide is entirely expelled which point is reached in Sample No. 31, the color changes to a black having a very slight tinge of sage green. This last color is the characteristic color of Portland cement clinker, but when ground to a fine powder becomes much lighter.

The great change in the operation has been the converting of a mechanical mixture of two substances, lime and clay, either of which alone or together have no cementing or hardening properties other than simply drying out into a chemical compound having cementing properties and power to crystalize or harden into rocklike hardness. This chemical change is not entirely accomplished until it has reached Sample No. 32 as is shown by the table of chemical analyses and also the chart of physical tests which follow.

Physical tests were made of samples No. 29, 30, 31, 32, 33, 34, and 35 with the results:—

Sample No.	Per cent. Fineness. 100 Mesh.	200 Mesh.	Setting Time. Initial.	Final.	Boiling Test.	Cold Water Test.	Specific Gravity.
29..........	98	82	30 min.	60 min.	Bad	Bad	2.94
30..........	99	84	45 "	90 "	Bad	Good	2.95
31..........	95	77	15 "	30 "	Good	OK	3.07
32..........	92	75	150 "	300 "	OK	OK	3.11
33..........	97	98.5	120 "	240 "	OK	OK	3.12
34..........	97	78	75 "	150 "	OK	OK	3.12
35..........	97.5	79	180 "	360 "	OK	OK	3.12

Tensile strength in pounds per square inch. Sand briquettes made of a mixture of one part of cement and three parts of standard sand. All the briquettes were kept moist in air during the first 24 hours and the rest of the time under water.

Sample No.	48 hrs. Neat	7 Days Neat	Sand	28 Days Neat	Sand	3 Months Neat	Sand	6 Months Neat	Sand
29......................	115	120	0	205	0	240	0	155	0
30......................	125	185	25	290	170	405	165	325	50
31......................	130	365	105	455	175	420	180	435	225
32......................	460	510	120	795	185	925	225	965	315
33......................	540	690	360	800	500	810	525	880	565
34......................	515	670	310	725	470	745	480	785	500
35......................	525	685	360	805	495	830	530	865	560

Tested by (Signed) F. J. Beal, Chemist.

Even as far back as sample No. 29, the cement mixture, though not entirely chemically combined, shows some cementing properties, but the amount of uncombined lime and other elements are enough to overcome in a short time and cause it to disintegrate and fall to pieces. When Sample No. 32 is reached the tests show that the chemical action is complete and that there is no uncombined lime, etc., in proportions large enough to cause the cement to disintegrate or crumble, and the result is a cement that will crystalize in a rocklike hardness and will retain this condition for all time.

(Signed) F. J. Beal, Engineering Chemist.

In conclusion I would express my thanks to my fellow employees, and the gentlemen who compose the Board of Scientific Advisers, and my appreciation of the support which the Board has through these years given to my efforts.

Dr. Rominger, the only one of my predecessors of longer term of service, passed away this year at the ripe age of 93, a fine specimen of that sturdy, intellectual and honest German stock which has contributed so much of value to the commonwealth.

Very respectfully,

ALFRED C. LANE.

INDEX.

A.

Page.
Agriculture, U. S. Department of, co-operation 9
Allegan county, soil survey 9
Alma, soil survey 9
Archambeau, T., coal drillings 16
Arenac county, Gregory's report 8

B.

Beal, F. J., cement analyses 23, 25
  cement burning 20
Bessemer, cross section north from 8
Biological Survey 11
Brissette, P., coal 16
Building 11

C.

Calcination of lime and clay mixtures to make Portland cement 21
Calumet survey 7
Campbell, E. D., Portland cement 20
Carboniferous fauna 10
Cass county, gravel 9
Cass soil survey 9
Cement and lime 19
Clathrodictyon vesiculosum 18
Clay and lime, calcination for Portland cement 21
Coal 15
Cooper, W. F., reference 10, 16
Co-operation, geological survey 9
Copper Range, section 8
Crataegus, Sargent's report 8

D.

Davis, C. A., peat report 8, 11, 15
  Tuscola county 8
Detroit, limestone 18
Dickinson county, surface geology 8
Drumlins, Northern Michigan 8

E.

East Tawas, old shore lines north 9
Edenville, coal drillings 17

F.

Fernekes, Dr. G., deeper mine waters 8
Finances 7

G.

Geib, W. J., Cass county gravel 9
Girty, Geo. H., carboniferous fauna 10
Glacial striae 18

Page

Gladwin, coal drilling, 17
Gordon, W. C., Bessemer work, 8
Grabau, A. W., Traverse group, 11
Gravel pits, 9
Green Bay, old shore lines, 9
Gregory, W. M., Arenac county report, 8
  old shore lines, 9

H.

Hankinson, T. L., Walnut Lake report, 8
Hawthorn, report on, 8
Hazlewood, A. J., coal waste examination, 10, 17
Highway Department, State, 9, 10
Hobbs, W. H., old shore lines, 9
Howell quadrangle, 7
Hunt, C. W., old shore lines, 9

I.

Iron county, surface geology, 8

J.

Jefferson, M. S. W., stream erosion, 11

K.

Kauffman, C. H., report on mushrooms, 11
Kawkawlin township, coal, 16
Kedzie, F. S., coal analyses, 16
Koenig, Dr., coal analyses, 16

L.

Lane, A. C., report, 1-25
Lansing, coal, 17
Legislative matters, 11
Lepidodendron aculeatum, 17
  clypeatum, 17
  obovatum, 17
Lepidostrobus variabilis, 17
Leverett, Frank, United States Geological Survey, 9
Lime and cement, 19
Lime and clay mixtures, calcination for Portland cement, 21
Limestone resources, 18, 19
Limestone, Saginaw Bay basin, 10

M.

Menominee county, surface geology, 8
Meuche, A. H., development of mining machinery, 8, 10
Milford quadrangle, 7
Mining machinery, development of, Meuche's report, 8
Missaukee county, coal, 17
Mt. Bohemia report, 11
Munising soil survey, 9
Mushrooms, report on, 11

N.

Neuropteris desorii, 17
Niagara limestone, 18

O.

Oakwood salt shaft, work on, 11
Old shore lines, 10
Osborn, Chase, limestone quarry, 18
Osceola county, coal, 17
Owosso soil survey, 9
Oxford soil survey, 9

Page.

P.

Parks, W. A., on Niagara fossils 18
Parr, S. W., coal 15
Peat, C. A. Davis 15
Physical tests, cement mixture 25
Pontiac quadrangle 7
Pontiac soil survey 9
Portland cement industry 19, 20
Publications 7

R.

Ries, H., report on molding sand 8
Road materials 9
Rochester quadrangle 7
Roscommon county, coal 17
Rotary cement kiln, analyses from 23
Russell, I. C., surface geology 7, 8

S.

Saginaw Bay basin, shale and limestone 10
Saginaw soil survey 9
Sand briquettes, tensile strength 25
Sargent, C. S., Crataegus 8
Shale, Saginaw Bay basin 10
Sherzer, W. H., Wayne county report 11
Smith, G. O., co-operation 10
State Highway Department 9

T.

Taylor, F. B., United States Geological Survey 9
Tensile strength, sand briquettes 25
Thornapple, report on 8
Topographic survey, finances 7
Traverse group, work on 11
Tricalcium silicate 19, 20
Tuscola, coal drilling 17
Tuscola county, Davis' report on 8, 11

U.

U. S. Geological Survey, topographic division, field work 9
Unionville, coal mine 17

W.

Walker, A. M., field work 9
Walnut Lake, report on 8, 11
Wayne county report 11
Wexford county, coal 17
White, A. H., Portland cement 20
White, David 17
Whitney, Milton, U. S. Department of Agriculture 9
Wight, Harry R., work 10
Williams, H. J., coal tests 15
Wolverine Shaft No. 3 17
Wright, F. E., Mt. Bohemia report 11
silicates 19

FOUNDRY SANDS

BY

HEINRICH RIES & J. A. ROSEN

LANSING, MICHIGAN
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5

LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGIST,
LANSING, MICHIGAN, May 6, 1908.

To the Honorable, the Board of Geological Survey of the State of Michigan:
Hon. Fred M. Warner, President.
Hon. D. M. Ferry, Jr.
Hon. L. L. Wright, Secretary.

Gentlemen—I herewith transmit to you for publication in your report for 1907 a paper primarily by Prof. H. Ries, of Cornell University, on the foundry or molding sands of the state. The field work and much of the laboratory work was done by him, but some aspirator tests made for him by J. A. Rosen at the Michigan Agricultural College, carefully conducted and admirably worked up, proved to be of such practical importance that Dr. Ries was very glad to add Mr. Rosen as co-author. It seems that porosity and permeability taken together give a factor which will grade a molding sand.

Very respectfully,
ALFRED C. LANE.

CONTENTS.

Introduction ... 41

Requisite qualities of molding sands:
- Cohesiveness ... 43
- Refractoriness ... 45
- Texture ... 46
- Permeability and porosity ... 56
- Effect of fluxes ... 59

The factor of quality ... 59

Life of a sand ... 61
- Chemical composition and its bearing ... 62
- Ultimate analyses ... 62
- Rational analyses ... 66

Mineral composition ... 66
- Quartz, clay, iron oxide, lime ... 66
- Miscellaneous ... 67

Notes on Michigan molding sand occurrence:
- Battle Creek, Dimondale, Escanaba, French Landing, Grand Rapids, Jackson, Lansing, Linden, Ludington, Marquette, Niles, Port Huron, Rochester, Saginaw, St. Joseph ... 67

LIST OF ILLUSTRATIONS.

PLATES.

I. Graphic representation of mechanical composition of molding sands. The number above each is the laboratory number.................. 48
II. Continuation of series shown in Plate I............................ 48
III. Chart showing mechanical composition and percentage of porosity of molding sands.. 52
IV. 1. Pocket of molding sand in moraine, Battle Creek................. 68
2. Silt sand bordering Kalamazoo river, near Battle Creek........... 68
V. 1. Sand bank at sand lime brick works near Jackson................ 72
2. Pits of Garden City Sand Co., Vineland, near St. Joseph............. 72

FIGURES.

1. Diagram showing Vinsonneau's method of mechanical analysis............ 47
2. Diagram showing graphic method of showing mechanical composition........ 48
3. Diagram showing the relation of the per cent of moisture to the rate of air flow.. 59

REPORT ON FOUNDRY SANDS.

By Heinrich Ries and J. A. Rosen.

INTRODUCTION.

The following report on foundry sands is based on field work done during July, 1906, and laboratory work carried on in the following winter. The field work was done by the senior author, and the samples collected by him were subjected to a mechanical analysis, and determination of their specific gravity and percentage porosity. In this work Mr. H. Leighton of Cornell University gave valuable aid.

It was deemed desirable, however, to test the permeability of the sands, and this work was later performed by Mr. J. A. Rosen of the Michigan Agricultural College, whose results indicate, as explained on a later page, that the average fineness as worked out in connection with the permeability test is perhaps on the whole more valuable than that calculated from the sieve test. This does not mean, however, that the mechanical analysis is valueless, or should be neglected.

Before going into the field an attempt was made to obtain as complete a list as possible of the Michigan molding sand producing localities, for the purpose of visiting them.

This list was compiled from replies to inquiries sent out to the foundries within the State. Information was requested as to the source of the sand used, the character of material cast in it, and for an expression of opinion regarding the relative value of Michigan or other sand for casting any particular kind of goods.

The replies received are by agreement treated confidentially, but it is no violation of confidence to base some generalizations on them.

A careful analysis of the replies received shows that by far the larger number of foundries in Michigan, including the larger ones, use sand obtained from other states, and that sand is being dug at but a few localities in Michigan. When a local supply is obtained it is usually of pockety character, and only sufficient to supply the needs of a small foundry.

Comparison of the sands obtained locally with those shipped in from other states show that the local sands are usually of coarser grain, but as will be shown later, some of those dug in Michigan compare not unfavorably with some of those shipped into the state.

A comparatively small number of localities in the states of Ohio, Indiana, Illinois and Kentucky are now supplying hundreds of foundries in the central and eastern states, with the finer grades of sand, and the consumption from these is enormous. Large as the deposits are, the material is not absolutely uniform, and much careful sorting and sometimes even blending has to be done.

If the fears expressed by many foundrymen are well founded, the time may not be so far distant when the supply of the high grade sands will become exhausted, and what will follow then, if predictions are correct, will be the production of artificial materials, made by the admixture of sand and clay in proper proportions. One of the difficulties of this will be the intimate and uniform mingling of clay and sand.

There occurs to the writer another process of treatment, which is somewhat the reverse of the one just mentioned. This is the conversion of some loams into a fine-grained molding material by the removal of a part of the clay by washing.

One may perhaps ask whether there is any need of waiting for the exhaustion of these present high-grade sands, purchased at such expense by many foundries. If the production of artificial sands by an admixing or a washing process is possible, it would seem that many local points of production of such a material could be developed, resulting in the placing of a much cheaper article on the market. It is interesting to note that not a few foundrymen look forward to the necessity of using artificial sands at no very distant date.

Another point that may be raised is, whether the unfavorable opinions held by some foundry men are always justified. Does a sand fail always because it is deficient in certain qualities, or may this apparent worthlessness be due to the fact that the molder does not understand how to use it? The experiments of Mr. Rosen on the optimum water content seem to have an important bearing on this point. Failure of the foundryman to recognize that the maximum permeability is not developed in all cases with the same amount of water added to the sand, might lead to failure in the use of a good sand.

The original plan contemplated an examination of all the Michigan localities reported, but before the field work was well under way it was found that at many of these but a small pocket of sand had been found, so attention was restricted to the more promising ones. Samples were not only taken from the pits visited, but some were collected of sands shipped in from other states, so that these might be compared with Michigan ones.

Under the term foundry sand there is included:

1. Sands for making the mold proper, into which the metal is cast, and
2. Core sand, utilized for making the cores, which occupy the hollow spaces of the cast piece.

It can be said in general, that while the molding sands proper are on the average of finer texture and more loamy than the core sands, still the two grades overlap, and both grades show considerable range of texture.

Thus in the selection of molding sands, the finer grained ones are used for small castings, with smooth surfaces, while heavy castings take coarser sands. If a coarse sand were used for making light work the product would have a rough skin, while the use of a fine sand for heavy work tends to make scabs, or cause blowing because the sand is so fine that it will not allow the gases to escape. There is, moreover, the danger of a fine sand forming a fused coating or scale on large castings which is difficult to remove. The finer core sands are not dissimilar to some of the medium or coarse-grained molding sands. In general, however, the core sands have much less clayey matter; they are lacking in a natural bond.

But in the selection of molding sands, it is necessary to consider not only the size of the casting, but also the kind of metal to be cast in it.

For steel casting a highly siliceous sand appears to be commonly employed; one with a silica content of 97% or over. A small amount of clay is added to this for bonding purposes.

For iron castings a loamy sand is chosen, whose texture varies with the size of the casting.

Brass and aluminum are cast in molds of fine grained loamy sands, the grades used being often similar to those chosen for stove plate. Bronze is cast in an imported sand of very fine grain and good bonding power.

One aim of the present report has been to make if possible an intelligent comparison of the Michigan sands with those shipped in from other states. Such comparisons can be based on either the chemical or physical properties of the molding sand, but in most cases the latter are the more valuable. Unfortunately no standard method of examination or testing has been adopted by the foundrymen, much as this is to be desired, and examinations of molding sand are confined largely to practical tests which are often time-consuming and costly.

With reference to the relative merits of a physical or chemical examination there is some difference of opinion among foundrymen.

A few buy their sand on the basis of composition, others may specify sand of a given texture, or both texture and composition may be considered; but the majority of foundrymen depend on the judgment of their foremen, who in many cases use purely empirical methods for determining the value of the material.

As the writer has remarked elsewhere,[1] satisfactory laboratory tests have been devised for the examination of other raw materials, and why can this not be done for molding sands.

Requisite qualities of molding sands.

In order to better discuss this it may be well to consider first what conditions foundry sands[2] are exposed to. Their properties may be enumerated as follows:

1. *Cohesiveness.*—The slightly moistened sand must possess sufficient cohesiveness to make the grains cohere when pressed together to form the parts of the mold. Core sands are usually deficient in this respect, and artificial bonds are supplied them.
2. *Refractoriness.*—A sufficient degree of refractoriness is necessary to prevent extensive fusion in the sand when exposed to the heat of the molten metal.
3. *Texture.*—The sands must possess the proper grain for the kind of castings that are to be made in them.
4. *Porosity and permeability.*—Sufficient porosity to permit the escape of the gases given off by the cooling metal is essential.
5. *Durability,* or sufficient length of life to permit as much of the sand as possible being used over again is important from the standpoint of economy.

These points may now be taken up in order.

Cohesiveness or bonding power.—A sand used for molding should when slightly moist possess sufficient cohesiveness to make the grains stick together following the removal of the pattern, and also to resist the pressure of the molten metal in the mold, or its corrosive action when poured into the mold. The cohesiveness of a sand depends probably in part on the amount of clayey matter which it contains, the character of the clay bond, and the texture. A finely-textured sand would, therefore, other things being equal, be likely to have a higher cohesiveness than a coarse-textured one.

---

[1] Wis. Geol. and Nat. Hist. Surv., Bull. XV.

[2] Under this head are included both mold and core sands.

At the same time, uniformity of distribution of the clayey matter is important. Sands containing little or no clay and of coarse texture, will cohere so little when moist that it will be necessary to add some artificial binder to them, as is done with many core sands.

The degree of cohesiveness of any given sand will naturally be somewhat affected by the degree of moisture which it contains, the particles of a moist sand cohering much better than those of a nearly dry one. An excess of moisture is, however, undesirable, as it causes the sand grains to pack too closely, an effect which is more noticeable in the finer-grained ones.

The cohesiveness may be tested by the tensile strength test, but the results do not in all cases appear to be satisfactory.

Experiments made by Parmelee[1] showed:

1. That the tensile strength increased with heavier tamping of the briquettes in molding, and
2. That there appeared to be no direct relation between average fineness. and tensile strength. The following figures from the New Jersey work show this.

Table showing tensile strength of molding sands.

Kind.	Per cent water required.	Tensile strength, lbs. per sq. in.		Average* fineness.
		Light. tamping.	Heavy tamping.	
No. 0 Albany	16.6	6.9	11.00	99.5
No. 1 Albany	11.4	2.95	5.50	98.1
No. 2 Albany	10.5	4.39	....	84.8
Barlow's unused	14.6	4.31	8.65	95.0
Barlow's used	11.1	.75	1.75	....
Sandy loam, Wilburtha, N. J	21.6	9.93	....	92.1
Sandy loam, Washington Crossing, N. J	12.8	4.58	11.50	88.6
Steel molding sand, Florence, N. J	5.2	1.59	....	79.5
Lumberton, N. J	11.2	36.37	61.50	81.4
Lumberton, N. J	15.1	15.37	20.25	67.2
Lumberton, N. J	9.9	22.10	50.30	73.4
Core sand, Burlington, N. J	11.4	52.56	....	42.2
Core sand, Burlington, N. J	6.7	4.62	8.30	46.1
Molding loam, Hainesport, N. J	10.4	9.70	17.25	72.8
Molding loam, Paxon & Co	11.2	32.04	40.50	78.6
Coarse loam, Hainesport, N. J	10.8	12.57	20.68	65
"Fine, mild" loam, Hainesport, N. J	10.1	10.35	19.50	76.6
"Strong" loam, Hainesport, N. J	7.9	23.72	42.13	74.4
Molding sand, Masonville, N. J	9.4	10.20	25.00	61.4
Heavy molding sand, Barton's Landing	10.9	44.57	59.25	69.6

*The average fineness was obtained by taking the average of the percentage retained on each sieve.

It will be noticed from this that the bonding power or tensile strength did not seem to stand in any direct relation to the degree of fineness, some of the coarser sea sands showing a higher tensile strength. The strength when dry is usually very low.

The chemical analysis throws but little light on the cohesive properties. A sand with an appreciable alumina content may frequently be quite plastic and cohesive, but others with an equal amount of alumina may be the opposite. Take for example the two following analyses. No. I is that of a well-known molding sand of fine grain, and much used throughout the eastern and central states, while No. II is a sandy brick clay, of sufficient cohesiveness and plasticity to be used for brick making.

---

[1] N. J. Geol. Surv., Ann Rept. 1904.

	I	II
SiO_2	79.36	90.00
Al_2O_3	9.36	4.5
Fe_2O_3	3.18	1.44
CaO	.44	.10
MgO	.27	.10
K_2O	2.19	tr
Na_2O	1.54	tr
TiO_2	.34	.70
H_2O	2.02	3.04
Moisture	.74	....
	99.44	99.88

Judging from the analyses some might conclude that No. I was more plastic and cohesive because of its lower silica and higher alumina content, whereas the reverse is true.

Refractoriness.—Foundry sands should be sufficiently refractory to prevent the pores closing up by fusion when the material is exposed to the heat of the molten metal. Were this to occur there would be no openings for the gases to escape and serious trouble would result. We might divide sands used for molding into two classes, viz., those used for steel casting and those used for casting iron and other metals. The former are exposed to a much higher heat, and consequently a very silicious material, running above 97% of silica is employed. They usually require the admixture of some clay for bonding purposes. The latter are not exposed to as high a heat, and need not be as refractory. They are, therefore, less pure, carrying between 70 and 80% SiO, and do not usually require a bonding material.

In every sand we can roughly divide the grains into two groups, i. e., the siliceous or refractory ones, and the clayey or non-refractory ones. If the sand contains only the former it will be very refractory (sand for steel castings), while if any clayey matter is present it will tend to flux with the silica grains (if heated high enough), this fluxing action being the more intense the finer grained the siliceous particles. Uniformity of mixture will likewise promote fusion changes. The predominance of fluxes in the finest particles is well brought out in the following partial analyses.[1]

Size mesh	60	80	100	100+Clay	
Silica (SiO_2)	95.92	94.35	94.66	91.06	61.54
Alumina (Al_2O_3)	1.29	1.47	1.47	4.57	23.16
Ferric oxide (Fe_2O_3)	.56	.56	.40	.80	1.60
Lime (CaO)	.10	.04	.34	.72	1.37
Magnesia (MgO) and alkalies by diff.	2.13	3.58	3.13	2.85	4.43
Loss on ignition	Undetermined.				7.90

In judging the refractoriness, appeal may again be made by some to the chemical analysis, but the writer questions whether it is safe to base too much confidence on this. A pure silica sand would be refractory, and one containing an appreciable quantity of alumina, iron oxide, lime, magnesia, and alkalies would be less so, the last four especially tending to depress the fusion point. The latter however does not stand in direct relation to the quantity of fluxes present.

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[1] Wis. Geol. and Nat. Hist. Surv., XV, p. 225, 1906.

Some foundrymen advance the view that lime increases the refractoriness of a sand. If the lime is uniformly distributed through the sand it does not. It has been found however that sprinkling a layer of lime on the interior of some parts of the mold seems to prevent its corrosion by the iron, or its fluxing of the sand by the molten metal. But in this case we have to deal with the behavior of the metal towards the lime alone (which by itself is refractory) and acts as a fire wall between the hot metal and the sand.

Texture.—This property is of primary importance. As has already been pointed out it may affect the cohesiveness of the sand. In addition to this, however, it stands in close relation to the permeability of the sand, and determines also to a large degree the grade of metal work that can be cast in it.

The texture of a sand is commonly determined by noting the percentage of each sample that is retained on sieves of different mesh. Most foundrymen in making such a determination rarely use anything finer than a 100 mesh sieve. The writer feels, however, that this is not sufficient, for the reason that there is considerable diversity of size among the smaller grains than 100 mesh. We might thus have grains ranging from fine sand down to clay, all of them under 1-100th of an inch. Fine sand or coarse silt, would tend to act somewhat like sand, and while it would decrease the size of the pores, need not necessarily lower the total amount of pore space. Clay, on the other hand, not only decreases the porosity, but tends to close the spaces between larger grains and renders the sand less permeable and more plastic.

It is therefore important to make some further separation of sizes under 1-100 in. This was done by drawing a dividing line at 1-250 in.

The method adopted for this report was as follows:

Fifty grams of the sand were put in an eight ounce bottle and the latter half filled with water. This mixture was then placed in a shaker for half an hour,[1] in order to disintegrate it after which it was washed through a set of 20, 40, 60, 80, and 100 mesh sieves. The sand retained on each was dried and weighed. That which passed through the 100 mesh was caught in a jar. When all the water and suspended matter had been run through the sieves the contents of the jar were stirred up and allowed to stand 45 seconds. That which settled in this time consists almost entirely of fine sand and silt grains, ranging from 1-150 to 1-250 in. in size and is classed as 1-250 in the table. The water with suspended clay was then decanted off. Since some clay is drawn down with the silty particles the process was repeated in order to get out the remaining clay.

The water over the silt and fine sand is removed in part by decantation and the residue evaporated to dryness. That with the clay is also evaporated to dryness.

It might be urged against the shaking method that there is danger of breaking up loosely cemented compound grains, but if there are any which are broken down by the half hour's shaking it is probable that they would also be crushed while the moist sand is being tamped into the flask for casting. Those that are too hard to be crushed are likely to escape disintegration in the shaker. Compound grains cemented either by iron or lime were in several cases found on the 20, 40, and 60 mesh sieves.

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[1] The author formerly kept the sand in the shaker for four hours, but has found that half an hour is sufficient to disintegrate most sands.

There are of course other methods employed for making a mechanical analysis to determine the texture.

Thus one commonly used and described by Mr. W. G. Scott consists in placing ten grams of sand on the 100 mesh sieve along with ten 7-16 in. steel ball bearing balls, and shaking with a circular motion for one minute. The sand passing through is weighed and credited to the 100 mesh sieve. The sand remaining on the meshes of the sieve, together with the balls, is emptied onto the 80 mesh sieve, the operation being repeated and so on up to the 20 mesh. The object of the steel balls is of course to break up any lumps or grains.

A similar method is advocated in the pamphlet on molding sand published by the International Correspondence School of Scranton.

Vinsonneau[1] has suggested the following method of mechanical analysis for the comparison of sands, which he terms the *decantation method.*

Two vessels are employed (Fig. 1), one, *a*, with a volume of *v*, and a larger one *A*.

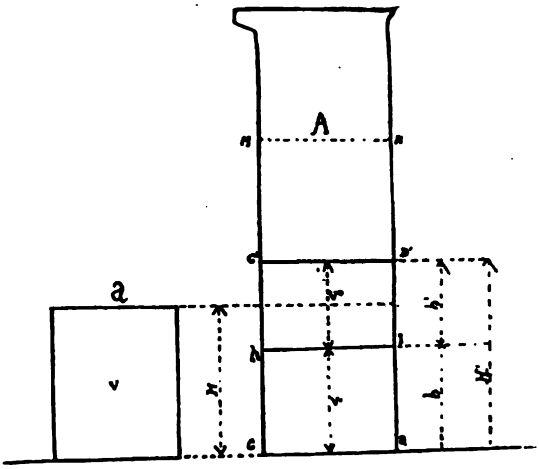

Fig. 1. Diagram showing Vinsonneau's method of mechanical analysis.

The vessel *a* is filled with sand, without tamping it in, and its contents then transferred to *A*, which is filled with water up to *mn*. The sand is then stirred up in the water and allowed to settle. In settling the heavier grains settle more rapidly, and accumulate in the lower portion of the vessel *A*, while the finer or lighter ones are on top. As a result of this the sand sample becomes divided into two portions. The one *c a h l* or v' and the other *h l c d* or v." Now v' v'' = v plus a certain increase in volume, which is characteristic of each sand. The part v' is the refractory part, and v'' or *h l c d* is the more aluminous or plastic portion.

Vinsonneau claims that in sands of the same strength the expression of $\frac{v'}{v''}$ is constant, and the strength is expressed by the ratio $\frac{H}{H'}$ representing the heights of the coarse and fine portions in the beaker.

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[1] Notes sur les Sable a mouler er sur leur emploi en fonderie. Bull. de. la Soc. D'Encouragement pour L'Industrie Nationale. Vol. 3, No. 2, p. 112, 1906.

It appears to us that this method might work if the sand sample contained but two sizes of grains, but where a number of different sizes is present, it seems doubtful if we can get a sharp line of division between c a h l and h l c d, and therefore obtain exact measurements.

Vinsonneau goes a step farther and claims that the heights obtained in two sands by the settling method are nearly proportional to their alumina contents.

The mechanical analysis expresses the textural qualities of the sand. Those of very fine texture will show a high percentage of the finer sized grains, while those of coarse texture will exhibit a correspondingly large quantity of coarse ones. That there is considerable variation in texture can be seen at once by reference to the mechanical analyses on p. 52.

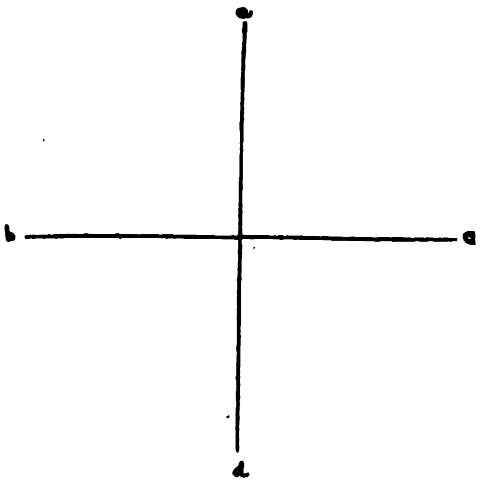

Fig. 2. Diagram showing graphic method of showing mechanical composition.

The writer has suggested elsewhere the possibility of expressing the texture graphically[1] to permit more rapid comparison of different sands. Fig. 2 represents the method used. On the four lines *a*, *b*, *c*, *d*, there are laid off equal distances corresponding to 100 per cent. On *a* the percentage of clay is laid off, on *b* the amount retained on 100 mesh, on *c* the percentage obtained by settling, and ranging from 1-100 to 1-250 in size, while on *d* the combined percentages of grains retained on the 20, 40, 60, and 80 meshes. These last four are combined as they represent the coarse particles of the sand. Having laid off the proportionate distances on the four lines, the points are connected by straight lines, and the resulting figure shows at a glance the texture of the sand.

Plates I and II represent the texture of all the sands examined for this report. In the very fine ones it will be noticed that most of the figure lies above the horizontal line *bc*, while in the very coarse ones it lies below the horizontal.

It is sometimes regarded as desirable to express the average fineness by means of a single number, instead of stating the entire mechanical analysis. Several methods based on the sieve test have been suggested, but all are open to the objection that the results obtained by the different methods are

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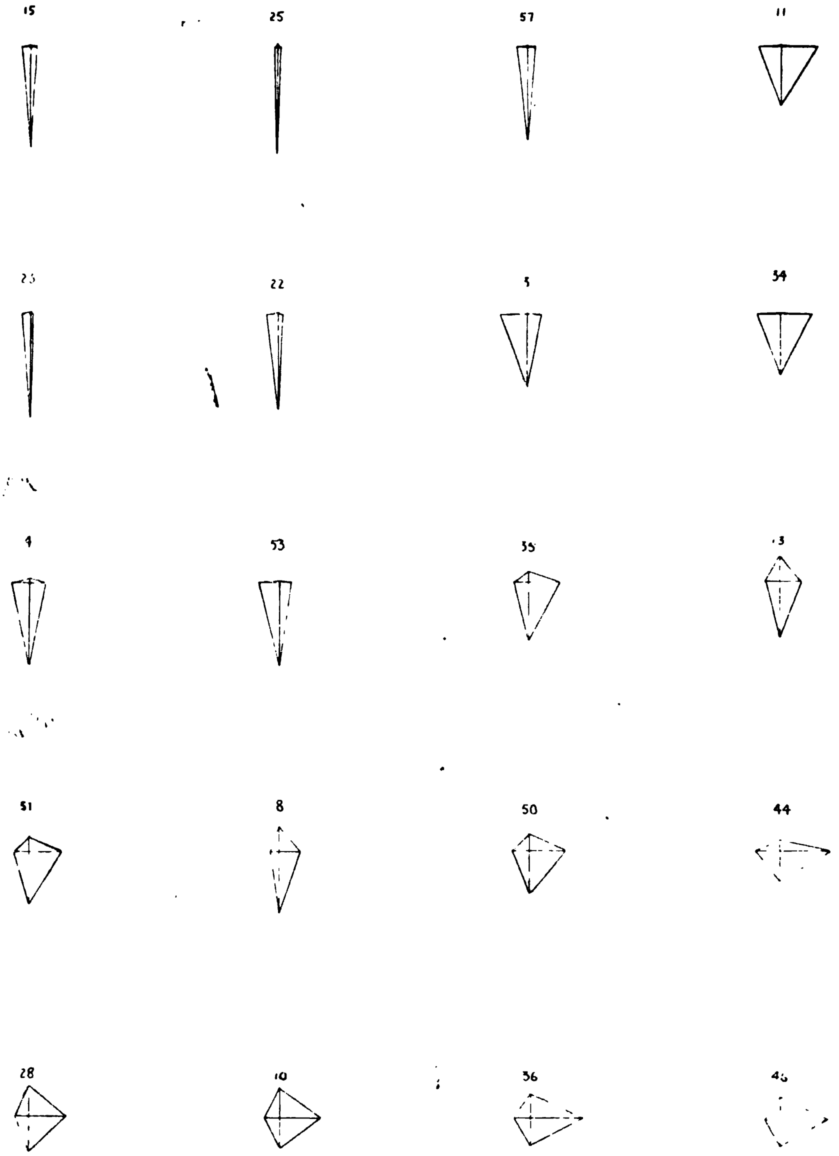
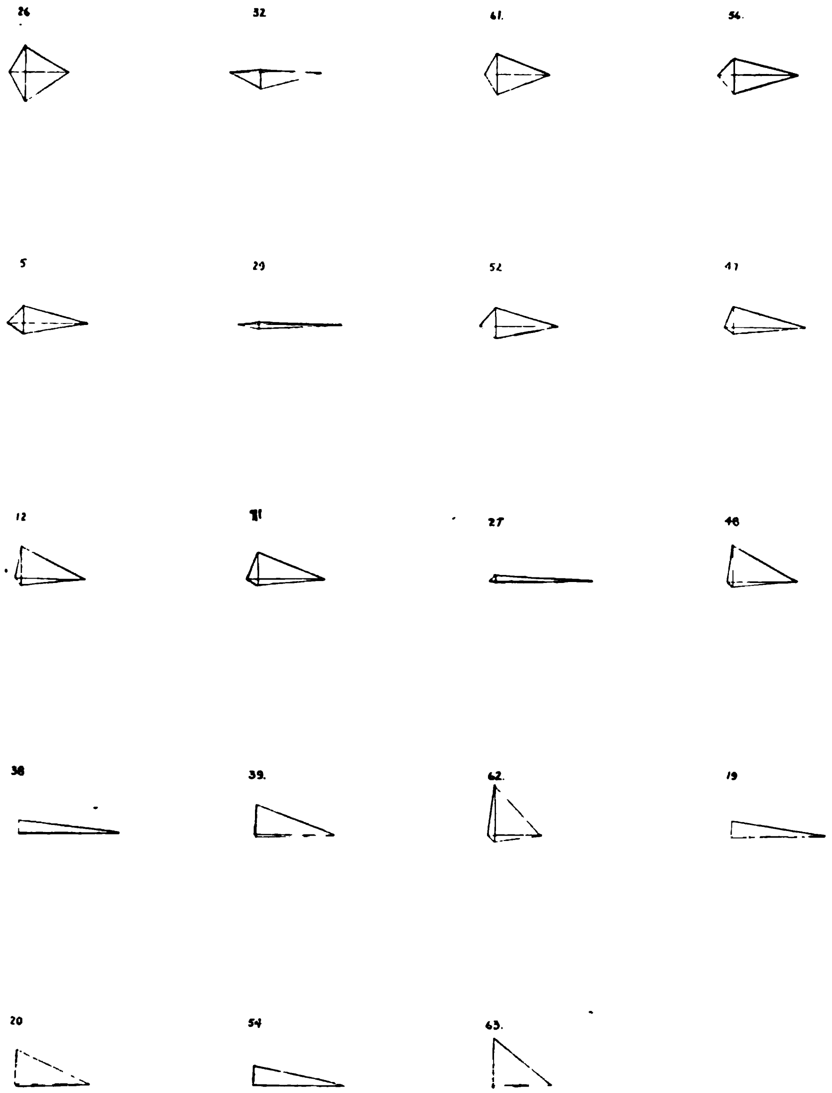
[1] Wis. Geol. and Nat. Hist. Survey, Bull. XV, p. 207, 1906.



GRAPHIC REPRESENTATION OF MECHANICAL COMPOSITION OF MOULDING SANDS.
THE NUMBER ABOVE EACH IS THE LABORATORY NUMBER.



CONTINUATION OF SERIES SHOWN IN PLATE I.

not comparable, and only those sands can be compared which have been screened by the same method.

One method used by many foundrymen, and described in the Textbook on Molding issued by the International Correspondence Schools of Scranton is as follows: A set of sieves, including 20, 40, 60, 80, and 100 mesh is used. Exactly 100 grams of sand is sifted one minute on the 100 mesh sieve; the part that goes through is weighed, and the balance sifted in the 80 mesh sieve, and the process repeated on all the other sizes of sieves. Any loss is credited to the 60 mesh sieve, and any that does not go through the 20 mesh sieve is credited to a 1 mesh sieve. The weights of sand going through each sieve are then multiplied by the mesh and the total divided by 100 which gives the degree of fineness.

The following example will more clearly illustrate the method and calculations:

Weight of sand passing through.		Number of mesh of sieve.	
55.22 grams	by	100 mesh	5,522.00
20.89 "	"	80 "	1,671.20
11.64 "	"	60 "	698.40
10.57 "	"	40 "	422.80
1.20 "	"	20 "	24.00
.06 "	"	1 "	.06
.42 "	"	60 "	25.20
100.00			8,353.36

Thus, 8,363.66 divided by 100 gives 83.64 per cent as the percentage of fineness.

By this method the sand is graded into five grades according to its fineness.

No.	Grade.	Degree of Fineness.
1	Superfine	Above 100 per cent.
2	Fine	90 to 100 per cent
3	Medium	75 to 90 per cent.
4	Coarse or heavy	55 to 75 per cent.
5	Extra coarse	30 to 55 per cent.

This method is very simple, but does not differentiate sufficiently the finer grades. Moreover, the average fineness calculated according to it could never exceed 100 per cent. The average fineness of the sands tested for this report was also determined by this method and is given in the table on p. 52.

Parmelee* has suggested taking the sum of the percentages passing each sieve, and dividing this by the number of sieves used. This gives us a figure which may be called the *per cent of fineness*, and serves as an approximate means of comparing sands with each other, provided "they have each been screened with the same set of sieves."

He points out, however, that the per cent of fineness of the same sand will vary with the number of screens used. Thus in one case the average fineness figured out 72.2 per cent when 20, 40, 60, 80, and 100 mesh sieves were employed, but when a 200 mesh was added to the set it changed the result to 61 per cent.

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*N. J. Geol. Surv., Ann. Rept. 1904, p. 209, 1905.

A method previously used by the writer is as follows: The average being defined as the sum of all the quantities considered divided by the number of separate items, we assume that if in a sand we have

N_1 grains of size S_1
N_2 grains of size S_2
N_3 grains of size S_3

$$\text{Then average size of } S = \frac{N_1S_1 + N_2S_2 + N_3S_3 + \ldots\ldots}{N_1 + N_2 + N_3 + \ldots\ldots\ldots\ldots}$$

If the total number of grains is N, then

$$N_1 + N_2 + N_3 \ldots\ldots\ldots\ldots\ldots\ldots = N$$

$$\text{And } S = \frac{N_1S_1 + N_2S_2 + N_3S_3 + \ldots\ldots}{N}$$

$$\text{or } \frac{N_1S_1}{N} + \frac{N_2S_2}{N} + \frac{N_3S_3}{N} + \ldots\ldots\ldots\ldots$$

But $\frac{N_1}{N}$ = the fractional part of the whole quantity which has the size S.

So if the total number is taken as 100 (or proportional to 100)

$\frac{N_1}{N}$ = Per cent size of S_1

and $\frac{N_2}{N}$ = Per cent size of S_2

For application of this to the mechanical analysis of a sand it is necessary to assume an average size for each mesh, and this of necessity makes the method approximate rather than exact. In the case of the grains retained on the 20 mesh it was assumed that they average 1-15 in., as few of them were somewhat larger. This size would be expressed decimally by .066.

Those which were retained on the 40 mesh might range from 1-20 to 1-40 in., and their average was taken as approximately

$$\frac{\frac{1}{20} + \frac{1}{40}}{2} = .037$$

and so on. The average size grain of the 1-250 in. was taken as

$$\frac{\frac{1}{150} + \frac{1}{250}}{2} = .005$$

The finest silt and clay was assumed as averaging .002. As an example: The mechanical analysis of one sand was

Mesh	
20	6.84
40	6.61
60	40.09
80	8.98
100	23.82
250	12.56
Clay	1.06
	99.96

$$\begin{array}{r}
.0684 \times .066 = .00451 \\
.0661 \times .037 = .00244 \\
.4009 \times .019 = .00762 \\
.0898 \times .013 = .00117 \\
.2382 \times .011 = .00262 \\
.1256 \times .007 = .00088 \\
.0106 \times .002 = .00002 \\
\hline
.01926 \text{ average grain size}
\end{array}$$

$$\frac{1}{.01926} = 51$$

In other words if all the grains in a given volume of the sand whose mechanical analysis is given above were reduced to a uniform size, they would pass through a 51 mesh.

In the accompanying table there are given the mechanical analyses of the sands made for this report, together with the average fineness, per cent porosity, and specific gravity. It will be seen that the majority of sands have a gravity so close to 2.6 that for all purposes this figure could be used in any calculations.

Lab. No.	On 20	On 40	On 60	On 80	On 100	On 250	Clay.	Average fineness.	Av. fineness Scranton method.	Sp. Gr.	Per cent porosity.
3	6.84	6.61	40.09	8.98	23.82	12.56	1.06	52	55	2.68	34.
4	3.96	7.10	46.97	11.74	15.32	11.35	3.65	55	54	2.65	35.
5	.06	.38	5.41	3.45	14.92	58.49	17.25	152	92	2.63	39.
7	.28	.56	1.93	1.80	9.34	60.78	25.27	180	95	2.6	42.
8	.96	12.42	34.41	4.31	7.50	18.29	22.06	69	65	2.61	35
10	3.29	3.05	15.49	4.24	12.64	35.19	26.11	95	81	2.64	43
11	11.13	12.08	21.93	4.33	19.16	30.01	1.35	49	60	2.68	30.
12	.30	.77	4.52	1.63	5.35	57.95	29.44	178	94	2.59	39.
13	4.69	13.34	23.96	5.01	11.95	18.22	22.79	63	66	2.66	42.
15	25.69	24.67	30.57	5.47	7.16	4.64	1.76	25	33	2.70	28.
19	.02	.20	.42	.09	.38	84.52	14.31	212	99	2.72	42
20	.09	.45	1.51	.31	.74	66.79	30.08	219	98	2.67	.....
22	.13	13.92	61.07	6.67	10.91	4.28	2.00	52	46	......	33.
23	.60	11.79	70.11	6.88	7.32	1.90	1.35	50	44	2.62	35.
25	19.13	39.45	29.68	2.68	2.99	2.47	3.36	29	30	2.72	33.
26	.13	.59	20.10	5.81	15.89	33.35	24.09	110	82	2.62	37.
27	.33	.18	.55	.24	5.47	87.92	5.36	181	98	2.65	43.
28	2.51	6.16	16.49	4.74	11.30	32.37	26.39	90	78	2.62	39.
29	.00	.08	1.79	1.03	19.42	74.93	2.71	155	94	2.66	35.
32	.00	.52	8.08	5.66	28.27	55.00	2.45	113	87	2.59	38.
34	9.46	7.38	24.99	8.49	19.48	26.67	2.92	54	62	2.52	30.
35	6.26	10.61	24.87	7.78	13.43	27.37	9.65	59	65	2.59	32.
36	1.68	3.08	14.00	4.66	11.59	44.47	20.50	106	83	2.6	39.
39	.27	.54	1.21	.32	1.21	69.46	26.97	209	98	......	38.
38	.08	.20	.17	.00	.14	87.56	11.82	205	99.6	2.7	45.
44	3.40	3.07	12.99	6.22	20.85	42.77	10.75	88	80	2.71	40.
46	1.36	3.44	14.78	4.24	12.82	40.74	21.64	107	82	2.48	43
47	.07	.24	3.47	1.78	8.42	66.21	19.78	176	95	2.61	43.
48	.29	.85	2.20	.65	3.52	58.37	34.08	201	97	2.62	41.
50	1.88	5.80	24.03	5.26	14.23	32.00	14.88	82	73	2.62	37.
51	5.82	6.74	27.39	5.75	12.55	27.54	12.74	65	67	2.63	36.
52	.11	.39	6.38	3.79	14.69	57.83	16.78	156	91	2.63	37.
53	1.14	9.42	50.76	9.73	17.30	10.44	1.17	57	42	2.63	36.
54	.09	.08	.29	.12	.57	79.02	18.41	220	99	2.73	38.
56	.03	1.08	13.21	2.08	9.53	57.70	15.06	135	88	2.6	37.
57	15.00	27.95	34.04	4.70	10.67	6.29	1.32	34	30	2.54	28
60	.29	.09	.23	.10	.56	95.59	1.64	241	......	......	38.
61	.54	2.11	11.38	3.94	11.67	49.57	20.57	127	87	......	37.4
62	.11	.32	2.93	2.59	5.96	41.87	45.23	211	95	2.61	40
Lane	.08	.71	1.65	.37	1.25	52.10	47.81	233	98	2.61	45.6

3. Fine core sand, Holton & Weatherwax Co., Jackson, Michigan.
4. Core sand, same locality as 3.
5. Under sand, Cory's pit, near Dimondale. Said to be of no value.
7. Molding sand from Reeve's pit, Lansing.
8. Eureka No. 4, from Zanesville, O., district. Used for general work.
10. Sand from town of Wells, near Escanaba.
11. Core sand and sand-lime brick sand, artificial mixture, Rochester.
12. Vrooman's pit, near Riverside.
13. Core sand, Niles.
15. Sand for car wheels, Rochester.
19. Fine-grained molding sand, Coldwater St., Battle Creek.
20. No. 2 Conneaut, Ohio. Used for stove plate.
22. Green sand for steel castings, from Ottawa, Ill.
23. Lake sand for cores, Lake St. Clair.
25. Core sand, near Jackson. Used also for sand-lime bricks.
26. Sand for general work, Garden City Sand Co., Vineland.
27. Leoni, 5 mi. N. E. of Jackson.
28. Heavier sand, Battle Creek.

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29. Fine sand, Rochester. Unused.
32. Light core sand, sand-lime brick pit, Saginaw.
34. Crushed quartz rock, Chalfonce, O. For steel casting.
35. Molding sand, F. Sadtler farm, Linden.
36. Reeves pit, near Lansing.
39. No. 5, Newport, Ky.
38. No. 3, Akron, O.
44. Christopher property, Lansing.
46. Town of Wells, near Escanaba.
47. Molding sand, Vornberg's property, Lansing.
48. Sand near cemetery, Port Huron. For general work.
50. Same locality as 10, but from east side of river.
51. Same locality as 10, but from east side of river.
52. Same as 5.
53. Core sand, McCamman property, Lansing.
54. From cut of L. S. & I. R. R., near Marquette.
56. Sand for general work, Kerlikowski's pit, Vineland.
57. Core sand, McCamman property, Lansing.
61. Sand for general work, Black Hills, Grand Rapids.
62. Ohio sand, for school furniture castings and as a substitute for 61.

While the full discussion of these sands is given on pages 66–78, the textural features may be mentioned here. Of the 39 sands whose mechanical analyses are given, 30 are from Michigan, and the others from outside localities. Six of these are listed as core sands, and their average fineness ranges from 29 to 113 on the author's scale, or from 30 to 87 on the Scranton scale. It will be seen from this that the core sands for some work are materially coarser than the molding sands for other work. A comparison of the average fineness figured by the two methods shows that the order of fineness remains about the same, but a serious objection to the Scranton method is that it does not differentiate sufficiently between the finer grades.

The method outlined above is, it seems to the authors, more satisfactory than the Scranton method, because it possesses greater accuracy, but it is open to the objection that the figures assumed for the average sizes have to be arbitrary, and in order to greatly reduce this error a very large number of sieves would have to be used. Moreover, the formula $1/L\ (1/n_1 + 1/n_2)$ is of necessity more or less hypothetical.

Again it is difficult to assume a satisfactory average size for clay by the sieve method. In many sands the particles which pass through the 250 mesh sieve are no smaller than the assumed average, while in other cases they are several times smaller.

Finally the error may be greatly increased if the percentage retained on any one sieve is very large.

DETERMINATION OF FINENESS BY ASPIRATOR METHOD.*

The method of determining the average fineness of a sand by means of an aspirator was devised by Prof. King in 1894, in order to determine what he called the effective size of soil grain. In addition to serving as a means of measuring the texture, it also determined the permeability of the material.

It had already been asserted that the rate of flow through sand was dependent upon the size of grain. Poiseuille had demonstrated, or it was thought he had, that the flow of liquids and gases through capillary tubes was proportional to the pressure.

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*This portion is the work of Mr. Rosen.

It was found further, that the weight of a given soil that could be packed in a given space was practically constant, and that therefore for a given soil the pore space was constant, and that fairly constant results were to be had in aspirating air through a given soil.

At this time Prof. King conceived the idea that the size of grain of a given soil might be determined in this way. The opinion of Prof. Slichter, Professor of Applied Mathematics at the University of Wisconsin, was asked as to the practicability of the plan, and so thoroughly did he believe in its possibility that he immediately set about developing a formula for making the necessary computation. He was so successful in this that measurements of soil grains have been made with an approach to accuracy that was at first hardly hoped for; and it is hoped that greater accuracy may still be secured as the method is further studied.

The apparatus used is the one figured in the Second Annual Report, Michigan Academy of Science, and is essentially the same as the one first used by Prof. King. It differs only in compactness of form. It consists of a soil tube (a), an aspirator of which (b) is the tank, and (c) the bell. The bell is lifted by the weight (d) by means of a cord (e) passing over the pulley (f). The tube (g) passes from the soil tube into the aspirator, and by way of this air is drawn by the aspirator through the soil in the tube (a). The dial (h) performs the function of air meter, and is calibrated for one litre in this case. The manometer or pressure gage (j) indicates the difference of pressure between the ends of the soil column in the tube, or conventionally speaking it indicates the pressure under which the air is drawn through the soil. It is connected with the air chamber (n) above (a). The height, cross section, inside volume, and weight of the tube (a) are carefully determined.

Before taking up the mode of operating the apparatus, let us consider briefly the points in Prof. Slichter's theory leading to his formula.

He considers a hypothetical soil having approximately spherical grains of nearly uniform size. The least pore space possible in such a soil occurs when the grains are so arranged that the element of volume is a polyhedron with face angles of 60° to 120°. In this case each grain of soil is in contact with other grains at 12 points, and the pore space equals twenty-five and ninety-five hundredths per cent. When the grains touch each other at eight points, the element of volume is a cube, and the pore space equals forty-seven and sixty-four hundredths per cent. Between these limits of arrangement we have a similar range of pore space and the face angle of the element of volume will be a function of the pore space and thus may be determined from it if the angle be known. The angle in actual practice can not be known, but conversely the pore space may readily be determined and the angle determined from it.

The length of pore in the soil is greater than the length, or height, of the soil column through which the air is aspirated and depends upon the angle as well as the height of the soil column. The cross section of the pore has for one of its functions the angle as well as the size of grain, and conversely the size of the grain will depend upon the cross section of the pore. The rate at which air may be aspirated through a soil will depend upon the size and length and number of its pores, upon the pressure under which it is forced through the pores, and upon the viscosity of the air which in turn depends upon the temperature of the air. The length of pore will depend, as before stated, upon the height of the soil column. The number of pore will depend upon the cross section of the soil column, whence we have derived the formula:

$$d^2 = K \frac{H}{spt} (8.9431 - 10)$$

Where d is the diameter of the soil grain,
K a factor dependent upon the per cent of pore space,
h height of soil column,
s cross section of soil column,
p pressure in c. m. of water,
t the time in seconds required to aspirate 5 liters of air at 20° centigrade, and (8.9431 — 10) is the logarithm of a constant.

Such a soil, however, as Prof. Slichter hypothecates is never found and probably seldom approached in nature. It is probably approached more nearly in form than in uniformity of size. But whatever the irregularities in a given soil, it is found, as has been partly stated before, that its minimum pore space and its power to allow the passage of a fluid through its pores are practically constant, and, as Prof. Slichter says: "It would probably be admitted that no matter how complex a soil may be there exists a certain ideal soil of uniform spherical grains that will transmit, under given conditions, the same amount of" fluid (he says water) "that would be transmitted by the complex soil. The size of the grain of this ideal soil of the same transmission capacity as the complex soil we shall call the effective size of grain of the complex soil." This is the term applied to the size of grain as determined by the new method.

THE MODE OF OPERATION.

To perform an analysis the soil is prepared by drying and pulverizing in a mortar, using a rubber pestle. It is then sifted through a 1 mm. mesh sieve to remove gravel.

It is then introduced into the tube (a), the end of which is provided with a tight fitting cap, and the tube held firmly upon some solid surface, and lightly tapped with a light mallet or stick. As the soil settles more soil is added, and this is continued until no further settling occurs. The surplus soil is stricken off, and that which remains is smoothed down with some plane surface. In Prof. King's laboratory a piece of ground glass is used for the purpose. The tube and contents are now weighed. Knowing the volume and weight of the tube, and the specific gravity of the soil, it is an easy matter to determine the pore space in the soil, and with the pore space determined, K (in the formula) is found by reference to a table.

On the other end of the tube (a) is now screwed a gauze cap, the tube is inverted, the solid cap removed, and the tube is screwed into place. The weight d is next suspended and this acting upon the bell causes the aspiration of the air through the soil. The manometer indicates the pressure under which the air is drawn through the soil. Usually the initial and final pressures are recorded, and the average of the two taken as p in the formula. The pressure should not much exceed three centimeters of water.

The initial and final time are noted and the time required to aspirate one or more liters of air through the soil is determined by subtracting the initial from the final time, and is expressed in seconds. If only one liter is aspirated then the time must be multiplied by five. Substituting those values in the formula, d is readily determined."

In the table below are given the average size of grain determined by all three methods, in which the different results obtained by the three are strikingly brought out.

By the aspirator method the average size of the grain passing through No. 20 sieve was determined only.

In computing the size with the material "on 20" included, Mr. Ries' table of separations was used for taxing the per cent "on 20." It will be noted that in most cases it makes little or no difference.

To compute the size in terms of sieves the following formula was applied:

$$1 + \frac{\text{size in mm.}}{25.4} = \text{size in terms of sieves.}$$

MECHANICAL ANALYSES OF SOME MOLDING SANDS.

No.	Weight of sand.	Spec. Grav.	% of pore space.	°Logar. of K.	Pressure in c. m.	Time in sec.	°Average size in m.m.	Average size of grain in terms of sieves.		Size of grain in terms of sieves.		% of "Clay."	% of material "on No. 250" sieve.
								"On 20" exclusive.	"On 20" inclusive.	Ries' method.	Scranton method.		
3.....	171.9	2.68	36.2	1.4512	1.85	1900	0.2630	97	91	52	55	1.06	12.56
4.....	171.2	2.65	35.6	1.4755	2.00	2400	0.2040	125	120	55	54	3.65	11.35
5.....	152.9	2.63	42.1	1.2340	2.00	15000	0.0681	407	407	152	92	17.25	58.49
8.....	160.5	2.61	38.8	1.3521	2.00	60000	0.0352	714	714	69	65	22.06	18.29
10.....	141.9	2.64	46.8	1.0795	2.12	16500	0.0480	526	509	95	81	26.11	35.19
11.....	184.2	2.68	31.7	1.6414	2.00	5450	0.1640	156	140	49	60	1.35	30.01
12.....	154.2	2.59	40.9	1.2760	2.00	60000	0.0324	770	770	178	94	29.44	57.95
13.....	147.2	2.66	45.0	1.1370	1.80	4200	0.1100	232	222	63	66	22.79	18.22
15.....	184.4	2.70	32.1	1.6234	2.20	1250	0.1060	238	182	25	33	1.76	4.64
20.....	155.1	2.67	42.2	1.2305	2.00	165000	0.0185	1429	1429	219	98	30.08	66.79
22.....	177.8	2.60	31.9	1.6323	2.20	1220	0.3405	74	74	52	46	2.00	4.28
23.....	175.8	2.62	33.3	1.5716	2.20	1200	0.1040	244	243	50	44	1.35	1.90
25.....	176.3	2.72	36.2	1.4512	2.20	775	0.3900	65	56	29	30	3.36	2.47
27.....	149.2	2.65	43.0	1.2024	2.00	9600	0.0745	345	344	181	98	5.36	87.92
28.....	152.2	2.65	42.9	1.2064	2.00	11100	0.0696	370	361	90	78	26.39	32.37
29.....	169.2	2.66	35.7	1.4714	1.85	15000	0.0885	286	286	155	94	2.71	74.93
32.....	163.6	2.59	36.8	1.4272	2.00	7200	0.1115	230	230	113	87	2.45	55.00
38.....	144.7	2.70	46.7	1.0828	2.00	33000	0.0350	714	714	205	99	11.82	87.56
34.....	174.2	2.52	31.3	1.6596	2.00	7200	0.1410	191	174	54	62	2.92	26.67
44.....	150.4	2.71	44.8	1.1334	2.00	6600	0.0840	303	292	88	80	10.75	42.77
46.....	139.1	2.48	46.2	1.0992	2.00	13200	0.0585	435	428	107	82	21.64	40.74
47.....	142.8	2.61	45.6	1.1183	2.00	5300	0.0912	274	274	176	95	19.78	66.21
50.....	158.1	2.62	40.0	1.1945	2.20	16320	0.0573	435	427	82	73	14.88	32.00
51.....	158.3	2.63	40.1	1.3043	2.10	12000	0.0749	345	326	65	67	12.74	27.54
52.....	161.8	2.63	38.9	1.3482	2.00	28800	0.0509	500	500	156	91	16.78	57.83
53.....	173.8	2.63	34.3	1.5286	2.20	2000	0.2365	107	106	57	42	1.17	10.44
56.....	160.3	2.60	38.7	1.3556	2.20	12100	0.0792	319	319	135	88	15.06	57.70
57.....	183.7	2.54	28.1	1.8146	2.20	1225	0.3750	66	59	34	30	1.32	6.29
62.....	159.2	2.61	39.3	1.3335	2.50	76800	0.0274	909	908	211	95	45.23	41.87

Permeability and porosity.—The permeability of a sand may be defined as the property which it possesses of allowing liquids or gases to filter through it. The porosity can be defined as the volume of pore space between the grains. These two properties are therefore different and should not be confused.

Two sands might have exactly the same percentage of pore space, but vary in their permeability, and other things being equal, the one with the larger pores should be more permeable.

Again a sand might have a large total pore space, but owing to the smallness of the pores its permeability might be low.

The permeability of a sand will be influenced by several things, such as tightness of packing or tamping, size of grains, water content and fluxing impurities in the sand. The first two factors operate throughout the period of use in the mold, the third only while the sand is moist, and the fourth only after it has been exposed to the heat of the molten metal.

Clay if present in quantity tends to clog up the pores, and if the percentage of the coarser sizes remains the same, a decrease in silt grains, and increase in clay grains will reduce the porosity and permeability.

The two following sands are an example of this.

Lab. No.	38	39
On 20	.08	.27
40	.20	.54
60	.17	1.21
80	.00	.32
100	.14	1.21
250	87.56	69.46
Clay	11.82	26.97
Aver. fineness (Ries)	205	209
Per cent porosity	45.9	38.7

Both are in use at a foundry in Saginaw. The foundry superintendent states that No. 38 is the more porous, and permeable of the two, and allows the gases to escape more readily. This higher porosity is shown above, and is due evidently to the lower clay content. If the length of life of the sand is related to the clay content, then No. 38 should have a longer life than 39.

Another factor that should be considered in connection with the size of grain is the state of aggregation of the finer grains whether they be silt or clay. If these are separate they will pack much closer and tighter than if cemented or bunched together in the form of compound grains. Moreover such compound grains will because of their porous character raise the porosity of the mass.

From what has been said above several deductions of practical value can be made.

Tamping because it forces the grains into closer contact will decrease the pore space, but even so theoretic conditions can rarely be reached. Other things equal, sands of fair-sized grains pack closer than those of equi-sized grains.

The decrease in permeability under increased tamping may explain why some good sands behave badly when packed too tightly in the mold, refusing to allow the gases to escape and causing blow holes.

It would seem that the degree of tamping is perhaps too little considered in the use of sands. For example, one sand may yield excellent results with a given amount of tamping, but another one to yield good results may require less tamping. In trying this new sand this point may be overlooked, and the material be turned down as worthless because it was not properly handled.

Porosity alone cannot be used as a gauge of permeability, although it is probable that coarse texture combined with high porosity indicates good permeability.

The only sure way of determining the permeability is to actually measure it with the aspirator described on p. 53, and the results of a number of these determinations made by J. A. Rosen are given in the table on p. 56.

DETERMINATION OF THE OPTIMUM WATER CONTENT.

The permeability of a sand will also be influenced by the amount of water used in packing it. Foundrymen usually add a minimum quantity of water to the sand, in fact, just enough to make it cohere sufficiently, it being claimed by some that an excess fills the pores of the sand and thereby decreases its permeability.

At first glance it would seem that the addition of water to a sand would decrease its permeability to gases. In fact just the opposite is true up to a certain point.

Table D shows the rate of flow of air through two sands containing known percentages of moisture. In each case lots of 500 gr. of the air-dry sand were weighed out, the proper quantity of water added, thoroughly mixed and the moist sand sieved through a No. 8 sieve. The cylinder of the aspirator was filled by adding the moist sand in small portions and ramming it with a properly shaped piece of iron as nearly alike in each case as possible. The data obtained would seem to indicate that there is for each sand an optimum water content when the permeability is highest. After this optimum is passed the permeability again decreases. The explanation of the fact is that when the sand is dry the particles pack close together, and smaller ones fitting between the largest and reducing the porosity to the possible minimum. When water is added the particles readjust themselves, swell up, adhere to each other, forming a *spongy* mass with numerous passages, and the sand can not be packed so close as before. When an excess of water is added the sponges of grains fall apart, pack close, and the pore spaces fill with water. This behavior of the sands can be easily observed under a microscope with a stereoscopic arrangement.

Of course it would not do to fill the cylinder with dry sand to its full capacity and then add water. In this case the water would simply fill the pore spaces, there being no possibility for the grains to readjust themselves.

IMPORTANCE OF THE "OPTIMUM WATER CONTENT."

The practical importance of the determination of the optimum water content lies in the following facts:

1. It gives an idea how a given sand should be treated in regard to the addition of water when used for work.
2. It serves as a criterion of adhesiveness of the sand. From the above consideration it is evident that a low optimum goes with high adhesiveness. A very low optimum would indicate a high degree of genuine clay and inversely.

Since the chemical analysis of a sand can not supply the information concerning its adhesiveness a test like the above becomes of highest importance. Of course further investigations along this line are necessary.

TABLE D.

Table showing the (influence) relation of the per cent of moisture to the rate of air flow.

Sample No. 10.

Per cent of moisture.	Time required to draw one lit. of air. Seconds.
Air dry	3300
5%	2880
7%	1080
9%	640
11%	240
13%	305
15%	560
25%	4200

Sample No. 13.

Per cent of moisture.	Time required to draw one lit. of air. Seconds.
Air dry	840
5%	560
8%	240
10%	280
12%	320
15%	375
20%	3000

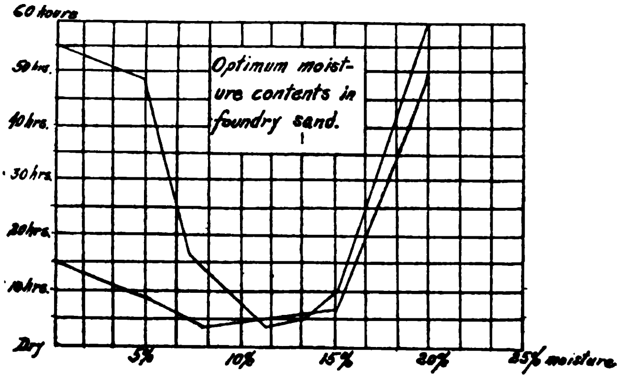

Fig. 3. Diagram showing the relation of the per cent of moisture to the rate of air flow.

Effect of fluxes.—The effect of fluxing impurities may show itself during the casting. If the clayey particles filling the interstices of the sand are sufficiently impure to fuse when heated by the molten metal, the coalescence of these in fusing would tend to close up the pores. For this reason partly a sand running high in fluxing impurities is undesirable.

The "factor of quality" of molding sands.—Granted the adhesiveness and refractoriness of a molding sand, its quality (for different purposes) would depend upon the fineness and its permeability, which can be measured by the rate of flow of air through a column of the sand. Considering the quality of the sand as a formation of its average fineness and permeability of rate of flow of air, we may express its "factor of quality" as the product of these two determinations. Thus let a, b, c, and d be the corresponding average fineness of four sands, and u, x, z, y, the times in equal units it takes to draw a given volume of air through an equal column of each of these sands. The ratio of the fineness of the sand then equals a:b:c:d; the rate of the flow of air being inversely proportional to the time it takes to draw an equal volume will be proportional to 1/u : 1/x : 1/z : 1/y, and the "factors of quality" of the sands will be in the ratio of a/u : b/x : c/z : d/y.

Table C shows the factors of quality of 14 samples of molding sands examined and distributed in the groups indicated by Mr. Jacob Siegrist of the Hildreth Manufacturing Company, a specialist foundry foreman. Within the groups the sands were placed by Mr. Siegrist in the same order as they are arranged in the table, except samples 52, 44, 47. Sample 47 was placed by him as No. 1 in the corresponding group, and 44 as No. 2. Sample 52 should be more properly classed as a brass core sand. The other sands tested were not considered good enough to be rated. The data would seem to indicate:

1. *That the quality factors as above determined of different groups differ from each other by the number of zeros preceding the first significant decimal.*
2. *That the groups blend into each other.*
3. *That the quality factor is a reliable indication of the relative desirability of sand within a given group.*

TABLE C.

Factors of quality of some molding sands. (Average fineness x ratio of air flow rate.)

No. of Sample.	Aver. fineness in mm.	Time in sec's.	Ratio of air flow rate.	Factor of quality.	Remarks.
	Fine sands for brass and very light iron work.				
20..........	0.0185	165000	1/1650	0.0000112	Grading agrees with that of practical molder, Mr. Siegrist.
62..........	0.0274	76800	1/768	0.0000356	
12..........	0.0324	60000	1/600	0.0000540	
8...........	0.0352	60000	1/600	0.0000587	
	Sands for general "medium" work.				
52..........	0.0509	28800	1/288	0.000180	This transition sand was included by Mr. Siegrist in the 1st group.
10..........	0.0480	16500	1/165	0.000210	
50..........	0.0573	16300	1/163	0.000350	
46..........	0.0585	13200	1/132	0.000440	
5..........	0.0681	15000	1/150	0.000450	
28..........	0.0696	11100	1/111	0.000630	
	Sands for heavier work.				
44..........	0.0840	6600	1/66	0.00127	These two were inverted in order by Mr. Siegrist.
47..........	0.0912	5300	1/53	0.00172	
13..........	0.1100	4200	1/42	0.00262	
4..........	0.2040	2400	1/24	0.00850	

There are a few comments which the senior author wishes to make regarding the foregoing table.

Samples Nos. 52 and 5 came from the same deposit, the lower stratum of Mr. Croy's pit near Dimondale. Through an oversight a mechanical analysis by sieves was made of each, the duplicates showing a remarkably close agreement (see table p. 52), and yet by the aspirator method the average fineness of one is given as 407 and the other as 500. Moreover the permeability of one is nearly twice as great as the other. It is also interesting to note that according to Mr. Croy's statement several foundries tried this lower stratum and pronounced it to be no good. The comment made on it on a later page is that it resembles some brass core sands used in the state.

Life of a sand.—Practically all molding sands after being exposed to the full heat of the molten metal lose some of their desirable qualities, and become "dead" as the foundryman calls it. A dead sand has had its cohesion and texture destroyed, but may have changed but little in its ultimate composition. In casting it is the layer of sand next to the metal which is most affected, and the thickness of this will depend on the size of the casting and temperature of the metal. On removing the flask from the casting it is impracticable to separate all of this burned sand from the unburned, and moreover there is no sharp line of division between the two, so that much of it gets mixed up with the unaltered material. Since it is deficient in bonding power, a small quantity of fresh sand has to be added to counteract it.

The deadness of the sand is no doubt due to several causes. In the first place the heat brings about a dehydration of the clayey particles of the sand, and thus destroys its plastic and bonding qualities. Secondly the heat may be sufficient to cause some or many of the grains to agglomerate by fusion, thus altering the texture. Thirdly, the iron may be reduced largely or in part to the ferric condition, but this change need not necessarily affect the physical properties of the material. From the first of these causes it would appear that a clayey sand (loam) would become dead sooner than a more siliceous one.

The length of a sand's life is a matter of some importance. Some sands can be used over several times without the admixture of fresh sand, while others are easily "burned."

In this connection the following analyses are of interest. No. I is an unused molding sand from Richmond, Va. It is much used for general work in the foundries at that locality and known as the Redford sand. No. II is some of the "dead" sand, from the layer next to the metal.

Per cent retained on mesh.	I	II
	Mechanical analysis.	
20	1.51	5.34
40	1.26	14.73
60	1.27	10.41
80	.56	1.28
100	6.27	14.61
250	71.69	59.37
Clay	16.52	3.52

Chemical analysis.

Silica (SiO_2)	83.49	82.32
Alumina (Al_2O_3)	7.25	7.80
Ferric oxide (Fe_2O_3)	4.71	3.98
Ferrous oxide (FeO)	......	2.38
Lime (CaO)	.36	.54
Magnesia (MgO)	.35	.41
Potash (K_2O)	1.30	1.64
Soda (Na_2O)	.41	.80
Titanium oxide (TiO_2)	.30	.22
Water (H_2O)	1.66	.19
Total	99.85	100.28

Comparison of these two sets of analyses indicate that there is a decided increase in coarseness of texture; due to fusing together of the particles. There was in fact a greater agglomeration even than is represented by the mechanical analysis, because some of the coarse grains have been screened out.

The chemical analysis shows little difference between the fresh and the used sand, except in its water percentage and in the iron contents, which have been in part reduced to ferrous oxide, and moreover the sand has apparently absorbed some iron from the metal during casting.

Chemical composition and its bearings.—There appears to be a difference of opinion among foundrymen who have considered the question, as to the value of a chemical analysis. Certain foundries buy their sand largely on chemical analysis, while others claim that it is absolutely worthless.

There are two types of chemical analyses, the ultimate and rational. The former resolves the sand into its component oxides, and takes no cognizance of the mineral compounds present. The latter separates the sand into its mineral compounds. The two should be considered separately.

Ultimate analysis.—Before discussing the bearings of the ultimate analysis it may be well to quote a number taken from different sources. These are given in the following table:

CHEMICAL ANALYSES OF MOLDING SANDS.

No.	SiO_2	Al_2O_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Ignition.	Miscellaneous.
1	81.58	6.46	4.94	.14	.22	1.19	.59	1.63	Moisture...1.46 TiO_2 .....1.90
2.	82.08	7.12	4.63	.36	.35	1.28	.41	1.66	Moisture...1.52 TiO_2 30
3	66.12	16.54	4.46	.40	.22	2.67	.35	4.90	Moisture...4.15 TiO_2 ..... .14
4	79.36	9.36	3.18	.44	.27	2.19	1.54	2.02	Moisture... .74 TiO_2...... .34
5	79.38	9.38	3.98	1.40	.54	1.80	1.04	2.50	Moisture... .80 TiO_2...... .44
6	70.40	3.80	14.94	.12	.15	1.95	.41	4.08	Moisture...3.77 TiO_2...... .70
7	84.40	7.56	2.52	.06	.21	1.29	.65	1.49	Moisture...1.76 TiO_2...... .44
8	85.04	5.90	3.18	.06	.14	1.65	.83	1.57	Moisture...1.11 TiO_2...... .78
9	70.24	16.62	3.94	.08	.09	1.41	.74	4.16	Moisture...2.42 TiO_2...... .46
10	71.60	11.49	7.81	.65	.95	1.42	1.27	4.00	
11	81.45	7.30	4.10	.90	.68	1.40	1.38	2.50	
12	85.08	5.10	4.00	1.20	.25	1.28	.34	2.65	
13	86.80	3.05	5.32	.15	.65	.83	.04	3.25	
14	84.28	4.50	6.10	trace ..	.72	.91	.39	3.10	
15	87.00	6.70	3.20	....	....	.25	.65	2.20	
16	81.26	5.69	4.29	4.34	.36	.87	.38	2.81	
17	88.52	5.63	.88	1.20	.83	By diff. .29		2.65	
18	79.41	12.47	.80	.99	.81	1.56		3.96	
19	90.68	5.95	.48	.69	.44	.71		1.05	
20	57.63	10.03	.88	11.16	5.63	.01		*14.66	
21	44.24	11.89	1.44	13.71	5.90	4.33		*18.49	
22	80.35	11.57	1.04	1.33	.66	2.60		2.45	
23	87.47	6.59	.80	1.18	1.10	2.26		.60	
24	79.61	11.21	2.48	.74	1.07	2.24		2.65	
25	81.50	9.88	3.14	1.04	.65	Undetermined		3.00	
26	84.86	7.03	2.18	.62	.98	Undetermined		2.20	
27	82.90	8.21	2.90	.62	.00	Undetermined		2.85	
28	79.8	10.00	4.44	.70	.88	Undetermined		2.89	
29	82.21	9.48	4.25	**.68	.32	.05	.09	2.64	Organic matter.28
30	86.85	8.27	2.32	**.29 .50	.81	.03	.10	1.08	Organic matter.15
31	88.40	6.30	2.00	.78	.50	....	....	1.73	MnO...... .23 Org....... .04
32	78.86	7.89	5.45	**1.46 .50	1.18	.09	.13	3.80	Org......... .64
33	81.57	11.52	2.74	1.49	.18	....	....	2.50	

*Includes CO_2.
**Carbonate.

1–2. Fine sand for light castings, Redford pits, Richmond, Va.

3. Coarse, gravelly sand for cores, Harbaugh's pit, Richmond, Va.

4. Albany sand for stove plate work, sampled from a foundry in Richmond, Va.

5. Same quality as 4, from Newport, Ky.

6. Sand for general casting work, Blandford pits, Petersburg, Va.

7. Sand for general work, Armstrong pits, Petersburg, Va.

8. Sand for general work, Griffin's pit, Fredericksburg, Va.

9. Sand for general work, Bottersea farm, Petersburg, Va.

Nos. 1–9 from Report on Mineral Resources of Virginia, by T. L. Watson.

10. "Philadelphia" brass sand.

11. Albany sand for brass work.

12. French statuary brass sand.
13. Mild Lumberton, N. J., brass sand.
14. Strong Lumberton, N. J., brass sand.
15. Millville, N. J., gravel.
16. Charlesville French brass sand.
    Nos. 10–16, J. L. Jones, The Foundry, Feb. 1907.
17. Core sand, Miltmore quarry, Janesville, Wis.
18. Upper bed, Rockton, Ill.
19. Nos. 2 sand, White and Traugott, Berlin, Wis.
20. Lower bed, Rockton, Ill.
21. Brass sand, Pendleton's pit, Neenah, Wis.
22. Loamy sand, Menominee Hydraulic Pressed-Brick Co., Menominee, Wis.
23. Lake sand for cores, Superior, Wis.
24. Fine sand, Albany, N. Y.
    Nos. 17–24, Wis. Geol. and Nat. Hist. Surv., Bull. XV, p. 224, 1906.
25. Fine sand.
26. Sand for medium weight castings.
27. Coarse sand for heavy castings.
28. Sand for heavy machinery in dry sand molds.
    Nos. 25–28, W. Ferguson, Iron Age, Vol. LX, p. 16, 1897.
29. Sand for light iron work, Scott.
30. Sand for medium iron work, Scott.
31. Sand for heavy iron work, Scott.
32. Sand for light brass work, Scott.
    From printed specifications of Case Company.
33. Sand for stove castings, Conneaut, O.

An examination of the above table shows us that while the analyses range from 44.24 to 90.68 in silica, about half of them show a silica contents between 75 and 85 per cent, while 21 of the 33 show over 80 per cent of silica. They can therefore with but two marked exceptions be classed as highly siliceous. None of these so far as known are used for steel castings, and moreover such sands would be more siliceous, running over 96 or 97 per cent silica. Omitting the calcareous ones there is usually a decrease in alumina with an increase in silica. Iron oxide may also show considerable variation, but the other four common ingredients, viz., lime, magnesia, potash, and soda are usually present in small amounts, the first two rarely exceeding 1 per cent individually, and the last two 2 per cent. While we must admit the existence therefore of some variation, the question arises whether it shows any relation to texture.

Mechanical analyses of all the above are not available, but there are a sufficient number to show that two sands of quite dissimilar texture may agree closely in chemical constitution. This is well brought out by the four examples given below.

	I	II	III	IV
SiO_2	79.36	79.38	84.40	85.04
Al_2O_3	9.36	9.38	7.50	5.90
Fe_2O_3	3.18	3.98	2.52	3.18
CaO	.44	1.40	.06	.06
MgO	.27	.54	.21	.14
K_2O	2.19	1.80	1.29	1.65
Na_2O	1.54	1.04	.65	.83
TiO_2	.34	.44	.44	.78
H_2O	2.02	2.50	1.49	1.57
Moisture	.74	.80	1.76	1.11
On 20	.26	.06	.09	.19
40	.51	.12	.41	.19
60	2.53	.32	2.21	.39
80	.99	.16	2.67	.19
100	4.19	.83	17.37	.98
150	79.85	73.38	58.20	81.92
Clay	11.24	24.73	19.02	15.97

I. Albany sand used for stove plate work, sample taken from foundry at Richmond, Va.
II. Stove plate sand, from Newport, Ky.
III. Sand for general work, Armstrong's pit, Petersburg, Va.
IV. Sand for general work, Griffin's pit, Fredericksburg, Va.

Nos. I and II agree closely in chemical composition, but differ markedly in their texture, the sizes showing the greatest difference being underscored. The difference in mechanical composition of III and IV is still more striking, although they are closely alike in chemical composition.

Other examples showing the lack of relation between textural and ultimate chemical composition could be found, but it is believed that the foregoing will suffice.

There is no relation between the percentage of alumina and the degree of plasticity. Analysis No. 3 in the foregoing table is that of a coarse grained, gravelly sand, while No. 9 is a fairly plastic loam.

Finally we may inquire whether there is any relation between the chemical analysis and use. Samples No. 10 and 13 (Table p. 63) are both brass sands, but are quite dissimilar in their silica and alumina contents. No. 20 is also said to be a brass sand, but bears no resemblance chemically to 10 or 13.

No. 4 and 28 are not dissimilar, and yet the former is a stove plate sand, and the latter a sand for heavy machinery.

Of course there are cases where two sands used for the same class of work are of similar composition, as Nos. 25 and 29, but they are exceptions.

Within very wide limits the chemical analysis may give us some clew to the degree of refractoriness. Thus Nos. 20 and 21 with their high percentage of fluxing impurities would not stand as much heat as a steel casting sand with 98 per cent silica, but among all the others it would be difficult if not impossible to make any predictions regarding their fire resisting qualities from the chemical analysis because texture plays such an important role, a coarse-grained sand of given composition being more refractory than a fine-grained one.

To sum up then regarding the chemical analysis it would appear to the writer that it gives us no information regarding the cohesiveness, degree of plasticity, texture or use, and we may therefore ask of what value it is. So far as I can see it is of little direct aid, except possibly in the selection of sand for steel casting. If a sand is very calcareous a drop of muriatic acid will show it without the need of making a complete chemical analysis.

Field[1] has stated that the ultimate analysis of a good molding sand[2] should give results within the following limits:

Total silica	75–85 per cent.
Alumina	7–10 per cent.
Lime below	2 per cent.
Alkalies below	5 per cent.
Iron oxide below	6 per cent.

These limits hardly fit all the sands in the table on p. 63, all of which, so far as could be ascertained are giving good satisfaction.

Rational analysis.—The rational analysis could in the writer's opinion be made of far more service than the ultimate one. As commonly made it determines the percentages of quartz, clay, and feldspar present, and might afford us clews regarding the bonding power, and refractoriness of the sand. Very few rational analyses of molding sand have been published. but the following two[3] may serve for purposes of illustration:

The ultimate analyses are also given.

	I	II
	Rational	analysis.
Quartz	67.85	64.66
Clay	17.50	24.50
Feldspar	10.12	7.28
Iron oxide	4.53	3.56
	Ultimate	analysis.
Silica	80.66	77.22
Alumina	9.30	9.26
Iron oxide	4.53	3.36

I. Sharp molding sand.
II. Strong molding sand.

Both of them carry considerable clay, and the strong one it will be noticed has nearly 25 per cent.

Mineral composition.—Although molding sands may contain a number of different minerals, those present in quantity are but few in number.

Quartz is invariably present in large amounts, forming angular or rounded grains, which vary in size from the fine silty grain up to particles the size of a pin head or even larger. The quartz grains may be white, but they are more generally colored by iron oxide, which frequently forms a film on their surface. Quartz may be regarded as the non-shrinkage and refractory element in the sand, and sands used for steel casting contain a high percentage of it.

The size of the quartz grains, moreover, determine the use of the sand to a large degree; since they influence its texture, and since the quartz grains are most influential in affecting the refractoriness and porosity, the percentage of them in the sand should be as high as is possible without displacing any bonding material, for the quartz alone has no bonding power, unless very fine, and even then its cohesiveness is exceedingly slight.

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[1] Iron Trade Review, Mar. 15, 1906, p. 19.
[2] He probably excludes highly siliceous sands for steel castings.
[3] Field loc. cit.

As explained on another page, the percentage of quartz present cannot be determined from the ordinary chemical analysis with any degree of accuracy.

A microscopic examination of almost any sand will show the predominnance of quartz among the sandy grains.

Clay, although not a mineral, correctly speaking, may be considered under this head. It is the most abundant substance next to quartz, and forms the bonding material in the sand. A certain amount of it is desirable, but an excess is exceedingly harmful, because it tends to fill up the pores between the sand grains, and cause the material to shrink and crack when heated. What we need then is sufficient only to properly bond the sand grains. It is in the clay that most of the fusible elements of the sand, such as lime, magnesia, alkalies, and even iron are found. Still the quantity of these will vary in different clays, and the best would be one of refractory character and therefore containing these in but small amounts.

Clays vary, moreover, in their tensile strength or bonding power, and the same amount of one clay might bond much better than an equal quantity of another. This is noticed in the difference in bonding power of two sands of like texture, and also when steel manufacturers use different clays for mixing with the same sand. The percentage of clay in the sand can be only approximately figured from the alumina contents in the ultimate analysis. A rational analysis would yield more accurate information.

Iron oxide.—This mineral is present in all molding sands, and gives them their reddish or brownish color. It may be present as a film coating the sand grains (the most common mode of occurrence), as a cement binding the grains together, as limonite grains or nodules, or as an ingredient of ferruginous silicates. The last two are rare. Most analyses show but a small percentage of it, and while it acts as a fluxing impurity, its action in many cases is not strong.

Lime is found in many molding sands, but usually in small amounts. It is probably present as an ingredient of feldspar grains, but in a few it occurs as lime carbonates, forming a cement which binds the grains together. It makes the sand more fusible, and when in the form of carbonate may also cause it to crack or crumble in the mold. The conditions under which it may act as a refractory agent are mentioned under refractoriness.

Miscellaneous minerals.—These are sometimes present in small quantities, and may include feldspar, mica, hornblende and a few others. The quantity is usually a negligible one, with the exception of mica, which is sometimes present in noticeable quantities.

NOTES ON MICHIGAN MOLDING SAND OCCURRENCES.

The deposits of molding sand worked in Michigan are all obtained from surface formations of recent geological age. They may occur, 1, as pockets in morainal drift; 2, as outwash deposits from the glacier; 3, as lake deposits as those at Vineland; or 4, as silts bordering the rivers, and representing either flood deposits of the present day or glacial material that has been reworked and sorted, etc. The method of formation, and therefore relation to deposits of other materials, is quite varied.

In no case has an extensive deposit of uniform character been observed, the deposits being usually either lenses or pockets, surrounded by coarser material (Pl. IV, Fig. 1), or thin beds (Pl. IV, Fig. 2) immediately underlying the surface.

In every case care is necessary in digging the material, as it may suddenly change in character without any warning. Several grades are often obtainable from a small area, and the person in charge of the digging should not only have an accurate knowledge of the character of the sand required, but keep a close watch on the excavating.

There are a large number of small foundries scattered over the state, which make castings of medium weight, and do not require a very high grade of sand, nor large quantities of it. While some of these obtain sands from other states, not a few use a local sand, which they are able to get from pockets scattered here and there over the country. Many of these were visited, but in every case the available supply was found to be too small to be worth listing.

In the following notes, therefore, it is the more important ones that are referred to.

Battle Creek, Calhoun Co.—There are a number of foundries located in this town which in the aggregate consume a large quantity of sand annually, and while much fine sand is shipped in from other states, nevertheless a considerable quantity is obtained from local pits, and used by the foundries at Battle Creek, notably by the Advance Threshing Machine Company.

These local sands, which do not so far as known form extensive deposits, are obtained in part from the glacial drift and in part from silty beds bordering the rivers. The latter are the more extensive. A pit may not last more than a few months, and then another one is sought and opened. Much of the sand used by the foundries is dug by Geo. Baltz, who also locates the pits. So when one pit is exhausted he hunts up another one.

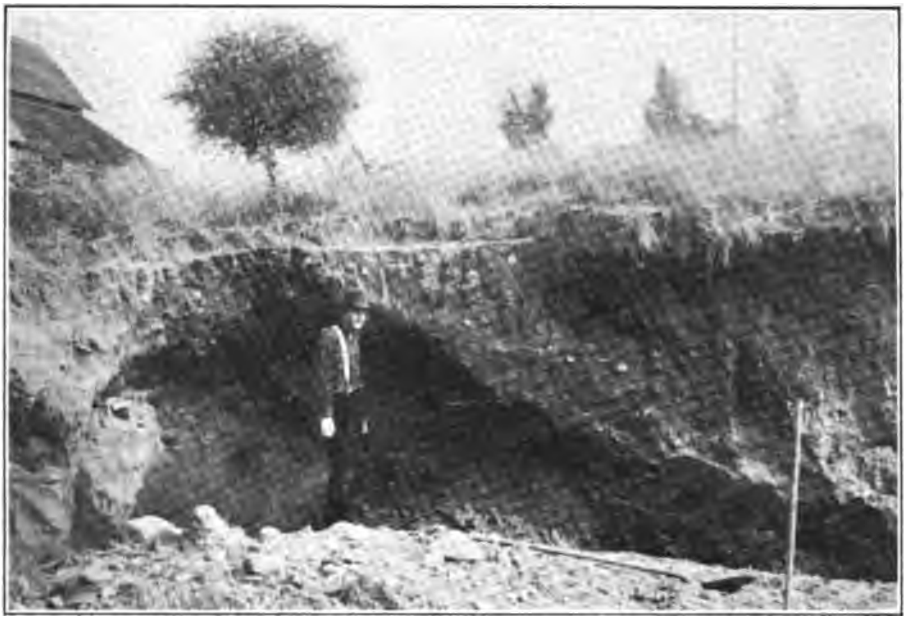
At the time of the writer's visit sand was being dug from a pit in the drift, located along Coldwater street, on the southern edge of the city, and just northwest of the mill pond.

The pit (Pl. IV, Fig. 1) shows an unassorted mass of dirt, very pebbly in its upper part, but containing pockets of molding sand, the one worked having a thickness of six to eight feet. Care has to be taken in digging the molding sand, as the deposit contains scattered streaks of coarse sand, which have to be thrown out.

The following mechanical analysis represents the texture of this material (Lab. No. 19).

Mesh.	Per cent.
20	.02
40	.20
60	.42
80	.09
100	.38
250	84.52
Clay	14.31
Average fineness (Ries)	212
Porosity	42

The sand, which is regarded as an excellent grade of "light" molding sand for bench work, is nevertheless a little too heavy for brass work. It



1. POCKET OF MOULDING SAND IN MORAINE, BATTLE CREEK.

2. SILT SAND BORDERING KALAMAZOO RIVER, NEAR BATTLE CREEK.

is very similar to No. 38 (Table p. 52) a sand from Akron, Ohio. The pit from which it was taken is but one of a number which have been worked around the city.

A more important deposit, but of the river silt type, occurs at Niagara Park, on the S. side of Battle Creek, (Pl. IV, Fig. 2). The pit is located in a field at a point about 600 feet east of the buggy factory and about ¼ mi. S. E. of the electric light plant.

The sand underlies a low terrace bordering the river, and whose surface is 6 to 8 feet above it. Its thickness ranges from 6 inches to 2 feet, and the overburden consists of 6–12 inches of soil. Gravel underlies the sand. The area shown in the view has been worked for about two years.

It is quite evident that in order to get any appreciable quantity of material a considerable area must be dug over.

The mechanical analysis of this sand (Lab. No. 28) was as follows:

On 20	2.51
40	6.16
60	16.49
80	4.74
100	11.30
250	32.37
Clay	26.39
Average fineness	361
Per cent porosity	39.6

This material is used for floor work. A similar sand has also been obtained on the south side of the Kalamazoo river, about 2 miles from town and along what is known as the River road, leading to Augusta.

Dimondale, Ingham Co.—Sand has been dug for several years, by P. Croy to supply the foundries at Lansing. The pit is located along the Grand river, on Mr. Croy's farm, and the deposit, which underlies the lower edge of the slope bordering the river, is probably a river silt, but is not being added to at the present time. The section involves

Loamy soil	1–2 ft.
Molding sand	2 ft.
Coarser sand	

The molding sand, which has been worked for 10–12 years is nearly exhausted at this point. Mr. Croy states that the underlying sand is no good, or at least not satisfactory to the Lansing foundries, but it closely resembles some of the brass core sand used in Michigan.

Its mechanical analysis, made in duplicate, yielded the following figures:

	5	52
On 20	.06	.11
40	.38	.39
60	5.41	6.38
80	3.45	3.79
100	14.92	14.69
250	58.49	57.83
Clay	17.25	16.78
Average fineness	407	500
Per cent porosity	39.6	37.5

Although Mr. Croy has prospected his farm rather carefully, he states that he has not been able to find any other deposits of molding sand on it, even along the river.

Escanaba, Delta Co.—There is a rather extensive deposit of molding sand in the town of Wells near Escanaba. The material, according to Prof. C. A. Davis, who collected the samples, is situated on the lower terrace of the Escanaba river. He writes, "This terrace is a limestone one, 15–20 feet high, made up of thin-bedded limestone with a covering of from 1–5 feet of silt. The rock is quarried, and it is in the vicinity of these quarries that the molding sand is taken. The sand is here only about 1 foot deep, the bottom of the stratum being rather coarser and gravelly, and also containing a good many limestone fragments. The area now being worked is only a small one, and not a great amount of it has been carted away, but the area underlain by this silt is considerable, and across the river it is much thicker, and appears to be of the same quality as that now used."

"The river terrace is subject to overflow in the spring freshets, and at such times the old silts are washed away and damaged by the bringing in of coarser sands and gravels.

Four samples were tested as follows: No. 10 was taken from the west side of the opening on the west bank of the river, now being used for the local foundry of the Stephenson Company. The deposit here was about one foot deep, with the lower two or three inches gravelly. The latter was rejected.

No. 46 was collected on the east side of the same opening about 15 yards from the last. Here, after removing about 4 inches of soil, 6–7 inches of silt was taken out.

No. 51 came from the east side of the river, about 20 feet above the river level, where it formed a layer 1 to 3 feet thick on top of the limestone of the I. Stephenson Company's quarry. The sample came from about a foot below the surface.

No. 50 was also taken from the deposit on the east side of the river about 30 or 40 rods south of the quarry and opposite the head of a small island in the river. There the silt deposit is from 4 to 6 feet deep. It contains some scattered limestone fragments.

The first two are used for ordinary foundry work, but the last two were taken from unworked beds.

The mechanical analyses are given below:

	10	46	51	50
20	3.29	1.36	5.82	1.88
40	3.05	3.44	6.74	5.80
60	15.49	14.78	27.39	24.03
80	4.24	4.24	5.75	5.26
100	12.64	12.82	12.55	14.23
250	35.19	40.74	27.54	32.00
Clay	26.11	21.64	12.74	14.88
Average fineness	509	428	326	427
Per cent porosity	43	43	36.3	37.4

From these analyses it will be seen that the material from opposite sides of the river is not only dissimilar, but that the sands from adjoining pits on the same side of the river are not closely alike. None of the materials are in use, but certain of these samples are not unlike others which are being employed.

Thus No. 10 is not unlike No. 28 (Table p. 52) which represents the heavier grade of Battle Creek sand in use at the foundries there. No. 46 is rather similar to No. 36, one of the Lansing sands. The other two are probably classable as fine core sands, or sands for heavier grades of molding. The occurrence of these sands is important, because they are among the few reported from the Upper Peninsula.

French Landing, Wayne Co.—A sand suitable for molding occurs along the creek on Stofledt's and adjoining farms. The material is a river silt but little of it has been dug, and that was for use at a small foundry at Romulus.

Grand Rapids, Kent Co.—Of the many foundries here, only a few use local sand, the majority reporting that they employ Ohio material, similar to that of No. 62 in the table on p. 52. The local sand used comes mostly from a morainal(?) ridge known as the Black Hills, and located along the Grandville Avenue trolley line. A number of small pits have been dug here and there, but none could be called permanent excavations, and some dissatisfaction has been expressed with the sand because it is said to show a tendency to burn onto the castings. The mechanical analysis of this material (61) is as follows:

Lab. No.	61	36
On 20	.54	1.68
40	2.11	3.08
60	11.38	14.00
80	3.94	4.66
100	11.67	11.59
250	49.57	44.47
Clay	20.57	20.00
Per cent porosity	37.4	39.1

This most closely resembles that from the Reeves pit (36) near Lansing, but is slightly finer.

Jackson, Jackson Co.—Very little sand for molding is worked in the immediate vicinity of Jackson, and the deposits are, so far as known, small.

The best local sand now used here, is some which comes from the W. McGill farm at Leoni, 5 mi. N. E. of Jackson, where a bed 2 ft. thick is worked after first removing the soil. The deposit is not extensive, however. It makes an excellent material for general work, and has been used for castings weighing up to three tons. While it is not as long lived as might be wished, it is claimed to have the advantage of leaving the casting quite clean and not adhering to it, in fact less so than the St. James sand. The following is its mechanical analysis:

Lab. No.	27
On 20	.33
40	.18
60	.55
80	.24
100	5.47
250	87.92
Clay	5.36
Average fineness	344
Porosity	43.9

Its high porosity and good permeability make it a good sand. It would be well to test this as a substitute for No. 38, which is brought from Ohio (see table p. 52).

Two miles west of Jackson a sand bank has been opened by the Jackson Pressed Brick Company for the manufacture of sand-lime brick. While the bank (Pl. V, Fig. 1) shows no sand adapted to molds, it does contain much that could be used for cores, as shown by the following mechanical analysis of a sample of it:

Lab. No.	25
On 20	19.13
40	39.45
60	29.68
80	2.68
100	2.99
250	2.47
Clay	3.36
Average fineness	29
Per cent porosity	33.8

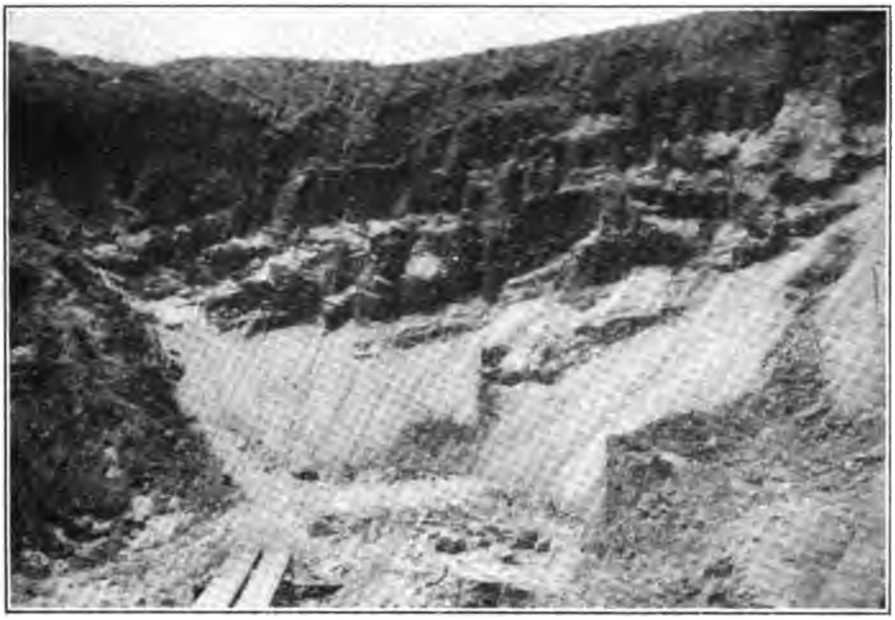
The Holton and Weatherwax Company get some sand from small pits in the drift around Jackson, and use it for general work. The drift also supplies core sands of different grades. Of the two given below, No. 4 is used for heavy work, and has of itself a fair bonding power, while No. 3 is a finer sand, and is employed for smaller cores. It is mixed with oil in the proportions of 1 oil to 35 sand by volume. The mechanical analysis shows its deficiency in clay bond.

Lab. No.	4	3
On 20	3.96	6.84
40	7.10	6.61
60	46.97	40.09
80	11.74	8.98
100	15.32	23.82
250	11.35	12.56
Clay	3.65	1.06
Average fineness	120	91
Per cent porosity	35.8	34.2

Lansing and vicinity, Ingham Co.—There are, perhaps, more local sources of supply of molding sand around Lansing, than are to be found around most towns, and some of it has been successfully used as a substitute for sands from other states.

For example the first of the following three mechanical analyses represents a sand from the Gillette property, 2 miles N. W. of Lansing, which is used as a substitute for a mixture of 2 and 3, formerly brought from Ohio.

	I	II	III
On 20	......	.04	.56
40	.01	.22	.93
60	.20	.88	9.59
80	.99	1.45	19.46
100	10.83	1.11	15.97
Through 100	87.90	96.30	53.49



1. SAND BANK AT SAND LIME BRICK WORKS NEAR JACKSON.

2. PITS OF GARDEN CITY SAND CO., VINELAND, NEAR ST. JOSEPH.

The section in the deposit which lies along the Grand River shows

Soil	1 ft.
Sand	2 ft.
Gravel	

The material, which underlies a narrow strip bordering the Grand river, is evidently a river silt deposited at some former period, and as one might expect, it varies somewhat in its texture from pit to pit.

Two different grades of washed over river silts are dug on the Reeves place 2½ miles west of Lansing. The first of these (Lab. No. 7) is used by the Hildreth Pump and Motor Works, and the second (Lab. No. 36) by the Lansing Wheelbarrow Works.

Lab. No.	7	36
On 20	.28	1.68
40	.56	3.08
60	1.93	14.00
80	1.80	4.66
100	9.34	11.59
250	60.78	44.47
Clay	25.27	20.00
Per cent porosity	42.6	39.1

A coarser grade adapted to core work occurs on the J. R. McCammans' place in the southeast part of Lansing. Two kinds are used by the Oldsmobile Company, and owing to their deficiency in bonding material (a characteristic feature of core sands), are mixed with from ⅛ to 1-20 flour. The mechanical analyses of these are as follows:

Lab. No.	53	57
On 20	1.14	15.00
40	9.42	27.95
60	50.76	34.04
80	9.73	4.70
100	17.30	10.67
250	10.44	6.29
Clay	1.17	1.32
Average fineness	106	59
Per cent porosity	36.8	28

The sand is stated by W. F. Cooper to be part of a kame-deposit.

Molding sand of the river silt type, similar in its mode of occurrence to that on the Reeves property, is found on the land of George Christopher, in the N. W. part of Lansing, and across the road from the School for the Blind. This had the following make up:

Lab. No.	44
On 20	3.40
40	3.07
60	12.99
80	6.22
100	20.85
250	42.77
Clay	10.75
Average fineness	292
Per cent porosity	40.7

A deposit not yet used is known to occur on the land of H. Vornberg, Lot 21, Lawrence subdivision, N. W. part of Lansing. On analysis it gave:

Lab. No.	47
On 20	.07
40	.24
60	3.47
80	1.78
100	8.42
250	66.21
Clay	19.78
Average fineness	274
Per cent porosity	43.8

Of the several other Lansing samples tested, this most closely resembles No. 7, from the Reeves property, but is a trifle coarser, having a little less clay.

Linden, Genesee Co.—More or less molding sand has been reported from this vicinity, but only a few small pits have been worked. These are all on the farm of Frank Sadtler, and the sand rarely runs over a foot in depth.

It is rather coarse textured, and used for general work. The mechanical analysis is No. 35 in the table on p. 52. The product is all shipped to a foundry at Fenton, where it is used with satisfaction for medium and heavy weight castings.

Ludington, Mason Co.—The sands reported from this region are largely windblown materials, and that used by the local foundries is obtained from Ohio.

Marquette, Marquette Co.—Samples were collected by Professor C. A. Davis from a railroad cut of the L. S. & I. R. R., a few miles from Marquette. The bed is exposed in the cut for about 300 feet, and has a steep face 30–40 feet high. The deposit lies in the N. W. ¼ of the N. E. ¼, Sec. 12, T. 48 N, R. 26 W., and about 400 feet above Lake Superior. It is part of a sand plain or delta deposited in a temporary glacial lake.

The mechanical analyses are as follows:

	54	60	I	II
20	.09	.29	......	......
40	.08	.09	.10	.02
60	.29	.23	.18	.04
80	.12	.10	.06	.02
100	.57	.56	.12	.14
250	79.02	95.59	77.50	77.54
Clay	18.41	1.64	22.40	22.12
Porosity	38.3	38.9	42.66	40.11

These are two of the finest grained sands tested from Michigan, and No. 54 agrees quite closely with some of the finer grained American stove-plate sands which are given for comparison. No. I above is the B. Y. sand from Hamilton County, Ohio., and No. II, a No. 5 sand from Newport, Kentucky. Both these contain a little more clay and show a slightly higher porosity. No. 60 will probably be found somewhat deficient in clay.

Niles, Berrien Co.—There are no large foundries at this locality and consequently the demand for molding sand is limited, so that there has been no encouragement to search for large deposits. There seems, however, to be a considerable quantity of loamy sand underlying the soil on all sides of the town, but in no case has a large pit been dug, and as soon as one is abandoned it washes in readily, obliterating the section. One such pit occurs just south of the Niles Milling Company on the Howard Rose property, near Dowagiac Creek; another is 3 miles south of Niles near the electric light plant. At the time of the writer's visit the Garden City Fan Company was digging sand for floor work, from a surface deposit underlying the soil, and adjoining the factory, while core sand is dug not 150 feet distant. The molding sand appears to occur as pockets resting in the coarser core sand. Excellent sand is also said to occur on the adjoining LaPeer property. The following mechanical analysis represents the local molding sand used at the Garden City Fan Company's works.

Lab. No.	13
On 20	4.69
40	13.34
60	23.96
80	5.01
100	11.95
250	18.22
Clay	22.79
Average fineness	222
Per cent porosity	42.3

A sand which is used in some quantity at one of the larger foundries is a coarse sand known as Eureka No. 4, from Zanesville, Ohio, district. In some respects it resembles the Niles sand rather closely, especially in the proportions of its finer material. There is some disagreement, however, in the larger sizes. No. 8 represents the Ohio sand and No. 13 the Niles material.

Lab. No.	8	13
On 20	.96	4.69
40	12.42	13.34
60	34.41	23.96
80	4.31	5.01
100	7.50	11.95
250	18.29	18.22
Clay	22.06	22.79
Average fineness	714	222
Per cent porosity	35	42.3

Port Huron, St. Clair Co.—All the foundries at Port Huron, with one exception, claim that while core sand can be found in the vicinity of Port Huron, molding sand has to be shipped from other localities, situated mostly in other states.

The only local sand reported is one dug from small scattered pits near the cemetery, and this is probably of lacustrine origin, similar to that worked at St. Joe. The material runs barely over a foot in thickness, however. It is interesting in being one of the finest textured sands examined from the state, and its presence should stimulate further search in the laminated sand and clay formation which borders the lakes. At present it is used for general work. The following is its mechanical analysis. (48).

Lab. No.	48	12	A
On 20	.29	.30	.04
40	.85	.77	.42
60	2.20	4.52	3.90
80	.65	1.63	1.92
100	3.52	5.35	6.12
250	58.37	57.95	56.72
Clay	34.08	29.44	31.02
Average fineness	......	770	......
Per cent porosity	41.2	39.5	40.43

Of the different Michigan sands tested it most closely resembles that from Vrooman's pit at Riverside, near St. Joseph, and of which analysis (12) is also given for purposes of comparison. It is also similar in texture to the Waterford, Ill., No. 3, which is said to be used for malleable iron castings and agricultural implements (No. A of above table).

Rochester, Oakland Co.—An extensive kame deposit of sand occurs along the Michigan Central R. R. about ½ mile S. E. of Rochester. Indeed this ridge extends along the railroad for some miles, but the material composing it is not always fine sands, and in fact any one pit may yield both sand and gravel.

The pit referred to above is worked by G. Heal, and the section involved is

1. Red loam	1½–2 ft.
2. Cross-bedded sand and gravel with pebbles up to 1½ in.	4 ft.
3. Sand	5 ft.

The beds may be used singly or mixed as indicated below. Beds 1 and 2 are mixed together and shipped to Detroit for use as cores in the car foundry. The third or bottom layer is also shipped to Detroit and used for cores.

A mixture of 1-10 No. 1 and 9-10 layer 2 is used for sand-lime brick manufacture.

The base of the pit is about 20 feet above the railroad track, and at the track level there is a 12 foot bed of fine sand exposed. This is covered by 2 feet sandy loam, and 1½ feet gravel. This is known as 100 fine and is shipped to several foundries in Detroit.

Underlying the bottom sand in the upper pit is 8 feet of blue sandy clay.

Another sand bed outcrops in the hill along the mill pond opposite Rochester station.

The following mechanical analyses were made of the sand in Heal's pit in Rochester.

No. 11 sand lime mixture referred to above.

No. 15, mixture of layer 1 and 2 for car foundry cores.

No. 29, No. 100 fine sand from along track.

	11	15	29
On 20	11.13	25.69	0.00
40	12.08	24.67	.08
60	21.93	30.57	1.79
80	4.33	5.47	1.03
100	19.16	7.16	19.42
250	30.01	4.64	74.93
Clay	1.35	1.76	2.71
Average fineness	140	56	286
Per cent porosity	30.6	28.4	35.2

Saginaw, Saginaw Co.—Although there are a number of foundries at Saginaw and Bay City, all of them report their inability to find a suitable sand for molding in the vicinity of these cities, and as far as could be ascertained none occurs. Light core sand does, however, occur in sufficient quantity in the valley at Saginaw, and much of that used is, it is said, obtained from the pit of the Sand Lime Brick Works near town. This, as will be seen from the following mechanical analysis, is a core sand of finer grain.

Lab. No.	32
On 20	.00
40	.52
60	8.08
80	5.66
100	28.27
250	55.00
Clay	2.45
Average fineness	230
Per cent porosity	38.6

The Bay City foundries report that some core sand is also dredged from the river.

St. Joseph, Berrien Co.—The region around St. Joseph is underlain by three important types of deposits. 1. Laminated sandy clays; 2. Loamy sands; 3. Dune sands.

Nos. 1 and 2 underlie the high terrace bordering the lake. Of these the clays form the thickest deposit, and extend from the lake level up to within a few feet of the terrace surface, and are overlain by the loamy sands. The dune sands are irregularly distributed, and are very prominent along the lake front.

Of these three materials the loamy sands are the only ones utilized for foundry purposes. These form a layer from one to three feet thick, immediately under the soil (Pl. V, Fig. 2). The deposit is not absolutely uniform, however, and more or less care has to be exercised in digging it, so that the layers or lenses of coarse sand can be thrown out. The main pits are at Vineland, south of St. Joseph, but the sand, which is shipped in large quantities, is known as St. James, Riverside, and even other names. The main producer is the Garden City Sand Company, which operates pits on the Tottske Brothers farm. Just north, on the adjoining property of Kerlikowski, is another extensive pit. In Vrooman's pits, which are nearer Riverside, the sand is somewhat more clayey.

The sand from this district is much used throughout Michigan and adjoining states, and in the main seems to give satisfaction for general work.

The following are a series of mechanical analyses of the product from this district.

Lab. No.	26	56	A	B	12
On 20	.13	.03	....	....	.30
40	.59	1.08	1.98	.54	.77
60	20.10	13.21	21.76	11.68	4.52
80	5.81	2.08	6.56	2.78	1.63
100	15.89	9.53	14.06	16.58	5.35
250	33.35	57.70	30.16	43.42	57.95
Clay	24.09	15.06	24.96	24.52	29.44
Average fineness	.....	319	.....	.....	770
Per cent porosity	37.5	37.4	40.60	46.45	39.5

No. 26. Sample taken in Garden City Sand Company's pits, near Vineland.

No. 56. Sample taken from car loaded at Kerlikowski's pits.

A. Sample of St. James sand from foundry at Grand Rapids, Wis. Wis. Geol. and Nat. Hist. Survey, Bull. XV, p. 206.

B. Sample supplied by Garden City Sand Company Ibid.

12. Vrooman's Riverside sand, sample taken from foundry at Saginaw.

INDEX.

INDEX.

A

Akron, Ohio........ 53, 60
Albany, molding sands........ 44, 63-65
Alkalies........ 66
Aluminum, sands for casting........ 43, 44, 48, 66
Analyses, chemical........ 45, 62, 63, 65
    mechanical........ 51, 56, 57, 61, 64, 65, 68-77
Analyses, ultimate........ 62, 66
Analysis, rational........ 66
Armstrong pits, Petersburg, Va........ 63, 65
Artificial sands........ 42
Aspirator method, determination of fineness........ 53

B

Baltz, Geo., Battle Creek molding sand........ 68
Barlow's, tensile strength, molding sands........ 44
Barton's Landing, heavy molding sand........ 44
Battle Creek molding sand........ 52, 68, 69, 71
Bay City, core sand........ 77
Berlin, Wisconsin, White and Traugott........ 64
Berrien county, sands from........ 74
Black Hills, Grand Rapids........ 53, 71
Blandford pits, Petersburg, Va., chemical analyses........ 63
Blowing, molding sands........ 42
Bonding power, sands........ 43
Battersea farm, Petersburg, Va........ 63
Brass, sands for........ 43, 63-65
Bronze, sands for casting........ 43
Burlington, N. J., core sand........ 44

C

Calhoun county, Battle Creek, molding sand........ 68
Car wheels, sand for........ 52
Chalfonce, Ohio, sand for steel casting........ 53
Charlesville French brass sand........ 64
Chemical analyses........ 45, 62, 63, 65
Chemical properties, molding sands........ 43, 44, 62, 64, 65
Christopher, Geo., property, Lansing........ 53, 73
Clay........ 67
Clayey sands........ 45
Coarse sand........ 42
Cohesiveness, molding sands........ 43, 44
Composition, mineral........ 66
Conneaut, O., stove plate molding sand........ 52, 64
Cooper, W. F., Lansing molding sands........ 73

Page

Core sand, 42, 44, 52, 53, 64, 72, 77
Croy's, P., pit, Dimondale, under sand, 52, 60, 61, 69, 70

D

Davis, C. A., molding sand, 70, 74
Decantation method, mechanical analysis, 47
Delta county, 70
Dimondale, P. Croy's pit, 52, 60, 69
Durability, molding sands, 43

E

Escanaba, sand from near, 52, 53, 70
Eureka No. 4, Zanesville, Ohio, 52

F

Fine sand, 42
Fineness and tensile strength, 44
Fineness, determination of, aspirator method, 53
Fineness (see texture).
Florence, N. J., steel molding sand, 44
Fluxes, 45, 65
  effect of, 59
Foundry sands, 41
Fredericksburg, Va., Griffin's pit, 63, 65
French Landing, sands, 71

G

Garden City Sand Co., 52, 75, 77, 78
Genesee county, 74
Gillette property, Lansing, 72
Grand Rapids, Black Hills, sand for general work, 53, 71
Griffin's pit, Fredericksburg, Va., 63, 65

H

Hainesport, N. J., molding loam, 44
Harbaugh's pit, chemical analysis, 63
Heal, G., Rochester, sand pit, 76
Hildreth Manufacturing Co., 60, 73
Holton and Weatherwax Co., core sand, 52, 72

I

Illinois, foundry sands, 41
Indiana, foundry sands, 41
Ingham county, 69, 72
International Correspondence School of Scranton, method of computing fineness, 47, 49
Iron casting, sands for, 42, 45
Iron oxide, 66, 67

J

Jackson, Michigan, core sand, 52, 71, 72
Janesville, Wisconsin, Miltmore quarry, core sand, 64

K

Kentucky, foundry sands, 41
Kerlikowski's pit, Vineland, 53, 77, 78
King, Prof., aspirator method for determining fineness, 53, 54

L — Page

- Lake St. Clair, core sand ... 52
- Lake sand ... 64
- L. S. & I. R. R., sand from cut ... 53, 74
- Lansing ... 71-73
  - Christopher property ... 53
  - McCamman property ... 53
  - Reeve's pit, molding sand ... 52, 53
  - Vornberg's, molding sand ... 53, 74
  - Wheelbarrow Co ... 73
- Leighton, H., work on foundry sands ... 41
- Leoni, Michigan ... 52, 71
- Life of a sand ... 61
- Lime ... 46, 66, 67
- Linden, molding sand ... 53, 74
- Liquids and gases, flow of ... 54
- Loam, sandy, tensile strength ... 44
- Loams, foundry sands ... 42, 44, 64
- Ludington, molding sand ... 74
- Lumberton, N. J., brass sand ... 64
  - tensile strength molding sand ... 44

M

- McCamman's, J. R., property, Lansing, core sand ... 53, 73
- McGill, W., foundry sand ... 71
- Marquette, sand near ... 53, 74
- Mason county ... 74
- Masonville, N. J., molding sand ... 44
- Mechanical analyses, composition ... 48, 50, 51, 56, 57, 61, 64, 65, 68-77
- Menominee loamy sand ... 64
- Method to determine fineness ... 49
- Michigan molding sand, occurrences ... 67
- Millville, N. J., gravel ... 64
- Miltmore quarry, Janesville, Wis., core sand ... 64
- Mineral composition ... 66
- Molding sands ... 42, 52, 56, 59, 61, 62, 66
- Molding sand, tensile strength ... 44, 53

N

- Neenah, Wis., Pendleton's pit ... 64
- Newport, Ky ... 53, 63, 65, 74
- Niles, core sand ... 52, 74, 75

O

- Occurrences, Michigan molding sand ... 67
- Ohio, foundry sands ... 41, 53
- Oldsmobile Co., core sands ... 73
- Optimum water content ... 42, 58
- Ottawa, Ill., sand for steel castings ... 52

P

- Parmelee, fineness, molding sand ... 49
  - tensile strength ... 44
- Paxon & Co., molding loam ... 44
- Pendleton's pit, Neenah, Wis ... 64
- Permeability, molding sands ... 43, 53, 56
- Petersburg, Va., Armstrong pits ... 63, 65
  - Blandford pits ... 63
  - Bottersea farm ... 63
- Philadelphia, brass sand ... 63

Page
Physical properties, molding sands... 43
Poiseuille, flow of liquids and gases... 54
Pore space... 55, 57
Porosity, molding sands... 43, 56
Port Huron, sand... 53, 75

Q

Qualities, requisite, molding sands... 43
Quality, factors of... 59, 60
Quartz... 66
Quartz rock, crushed, steel casting... 53

R

Rational analysis... 66
Redford sand... 61, 63
Reeve's pit, molding sand... 52, 53, 71, 73, 74
Refractoriness, molding sands... 43, 45, 65
Requisite qualities, molding sands... 43
Richmond, Va., analysis... 61, 63, 65
  Harbaugh's pit... 63
Ries, H., Foundry Sands... 41–78
Riverside, Vrooman's pit near... 52, 76, 78
Rochester, Michigan, core sand and sand-lime brick sand... 52, 53, 76
Rochester, sand for car wheels... 52
Rockton, Ill... 64
Rose, Howard, property, sands from... 75
Rosen, J. A., aspirator method... 53
  optimum water content... 42
  Foundry sands... 41–78

S

Sadtler, F., Linden, molding sand... 53
Saginaw, core sand... 53, 77
St. Joseph... 77
Sand, life of... 61
Sand-lime brick sand... 52, 53, 72
Sands, foundry... 41
Sandy loam, tensile strength, molding sands... 44
Scabs... 42
Scott, W. G., texture... 47
Shaking method, texture... 46
Siegrist, Jacob, "factors of quality"... 60
Sieves, terms of, size... 56
Silica... 64, 66
Siliceous sands... 45
Size, effective, of soil grain... 53
Slichter, Prof., size of soil grain... 54, 55
Soil grain, effective size of... 53, 54
Soil, hypothetical... 54
Standard method of examination... 43
Statuary brass sand... 64
Steel casting, sands for... 42, 44, 45, 52, 53, 64–66
Stephenson Co., molding sand... 70
Stove plate work, sand for... 63–65, 74
Superior, Wis., core lake sand... 64

T

Table, tensile strength, molding sands... 44
Tamping... 57
Tensile strength, cohesiveness... 44
  table showing... 44

Page
Texture (fineness), method of obtaining........ 49, 50
Texture, molding sands........ 43, 46, 48

U

Ultimate analysis........ 62, 66

V

Vineland, Garden City Sand Co........ 52, 77, 78
    Kerlikowski's pit........ 53
Vinsonneau, mechanical analysis........ 47, 48
Virginia, Mineral Resources of........ 63
Vornberg's, H., property, Lansing, molding sand........ 53, 74
Vrooman's pit at Riverside........ 52, 76-78

W

Washington Crossing, N. J., sandy loam........ 44
Water content, optimum........ 42
Watson, T. L., "Mineral Resources of Virginia,"........ 63
Wayne county........ 71
Wells, molding sand........ 52, 53, 70
White and Traugott, Berlin, Wis........ 64
Wilburtha, N. J., sandy loam........ 44

Z

Zanesville, Ohio, sand........ 52, 75

SUMMARY

OF THE

SURFACE GEOLOGY

OF

MICHIGAN.

BY

ALFRED C. LANE.

LANSING, MICHIGAN
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12

LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGIST,
LANSING, MICHIGAN, May 15, 1908.

To the Honorable the Board of Geological Survey of the State of Michigan:

HON. F. M. WARNER, *President.*
HON. D. M. FERRY, JR.
HON. L. L. WRIGHT, *Secretary.*

Gentlemen—I beg to submit the following report as an introduction to the surface geology of the State and its bearing on the study of the soils, surface deposits and physical geography, for the use of our public school teachers and their pupils, and as a key to the large scale maps of the surface geology which we are preparing.

Very respectfully,
ALFRED C. LANE.

TABLE OF CONTENTS.

Page

Introduction and acknowledgments 97

Economic importance of Surface Geology 97

Preglacial history 98

  Advance and cause of the ice age 98

  Effects of ice advance 101

  Deposits of the ice age 102

    1. Material produced by direct action of the ice 102

      a. Moraines 102

      b. Till plain 102

    2. By ice and water combined 102

      a. Eskers 103

      b. Kames 103

      c. Outwash aprons 103

    3. By water 104

      a. Glacial rock flour 104

      b. Gravels 104

  Walled Lakes 104

  Boulders 107

Recent deposits 108

  Lake deposits 108

  Polishing powder 109

  Road gravels 109

  Bog lime 109

  Peat 110

  River Silts 110

Connection of surface deposits and soils 110

Types of Michigan soils 110

  Dune sand 111

  Muck, peat and meadow 111

  Fine Soil Divisions of Department of Agriculture 113

    Clyde series 115

    Marshall gravel 117

    Superior soils 117

    Miami series 117

The Ice retreat 120

  The glacial lakes 122

  The retreat in Lake Michigan 123

    Lake Chicago 123

      a. Glenwood, 60 foot beach 123

      b. Calumet, 40 foot beach 123

  Retreat of the ice to the Saginaw valley 124

  Early lakes on the east side 126

    Lake Maumee 126

      a. Van Wert stage 126

      b. Leipsic stage 127

    Lake Arkona 128

Retreat of the ice from the northern highlands 128

  Lake Whittlesey—Belmore beaches 129

  Lake Saginaw 130

  Lake Warren 130

    Forest, and Grassmere beaches 130

Page
Lake Dana. Elkton, etc., beaches.................................... 132
Lake Algonquin. Toleston beach.................................... 132
Lake Nipissing.................................... 134
Recent lake system and shore lines.................................... 134
Changes now taking place.................................... 135

THE ICE AGE IN THE UPPER PENINSULA. 136

The thinly covered areas.................................... 137
The ice lobes.................................... 137
The first areas laid bare.................................... 139
Lake Jean Nicolet.................................... 139
Lake Duluth.................................... 140
Transitions from Lake Duluth.................................... 140
Lakes in Ontonagon Valley.................................... 141
The western end of Lake Algonquin.................................... 142
The early Lake Superior.................................... 143

LIST OF ILLUSTRATIONS.*

PLATES.

Facing Page

VI. Bed rock geology of Lower Peninsula, showing also by contours of the rock surface the preglacial valleys.................................... 89

VII. Ice smoothed outcrops:

A. Striated quartzite with crescentic cracks.................... 104

B. Drumlin.. 104

VIII. Beach deposits, gravels. Algonquin beach gravels, exposed by present cutting... 120

IX. Surface geology of Lapeer county................................ 128

X. Till or boulder clay.. 132

XI. Undercutting and recession of Algonquin terrace level at Point aux Barques.. 136

XII. Surface geology of Lower Peninsula............................ 144

FIGURES.

Page

4. Extent to which the ice sheet covered North America. From Chamberlin & Salisbury's Geology.. 99

5. Formation of eskers and swamps adjacent........................ 103

6. Boulder wall on spit. Lake Antoine after Credner................ 105

7. Cross section of boulder wall, Lake Antoine, after Credner...... 105

8. Cross section of boulder wall, after C. H. Gordon, Vol. VII, Part III, Fig. 2 106

9. Sketch map of the moraines left by the Erie-Huron lobe, after Leverett.. 121

10. Course of drainage from Southern Michigan by way of the Kankakee, after Leverett.. 124

11. Course of drainage from Southern Michigan by way of the Lake Chicago, after Leverett.. 125

12. Course of drainage from Southern Michigan by way of Lake Maumee and Lake Chicago, after Leverett..................................... 126

13. Course of drainage by the Imlay outlet and Grand River valley (Pewamo outlet)... 127

14. Lake Whittlesey and the Ubly outlet, after Leverett............. 129

15. Lake Warren, according to Leverett............................. 131

N. B.—Earlier writers, e. g., Lawson, used the term Warren in a broader sense.

16. Diagram to illustrate the naming of the lobes of the retiring ice sheet, and the lakes and outlets in front of them........................ 138

17. The Porcupine Mountains from the mouth of Black River. The "lake hill" or terrace 702, A. T.. 142

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*Plate VI and figures 9-15 are used with the permission of the Director U. S. Geological Survey.

SURFACE GEOLOGY OF MICHIGAN.

INTRODUCTION AND ACKNOWLEDGMENTS.

The writer does not pretend to have made a special study of the surface geology of Michigan, upon which others, especially Mr. Frank Leverett, are better qualified by their labors to write. These labors give to the maps which this report is to accompany most of their value, but Mr. Leverett is just now in Europe, and the writer's very lack of familiarity with the detail and technical points may help him in preparing this general report for popular use. Of course he has been more or less familiar with both parts of the State and the surface geology thereof for a number of years; he trusts enough so to interpret the work of others. It will not be necessary to give a long historical introduction, because Mr. Leverett has done that in a review of the glacial geology of Michigan published by the Michigan Academy of Science in 1904, sixth annual report, page 100. He has also given an account of the surface geology of the Ann Arbor region in the Ann Arbor folio, recently issued by the U. S. Geological survey, which is of value for the whole Lower Peninsula.

It may be well, however, to say for the benefit of teachers and others who wish to look up even later results that they will be found in Michigan, Wisconsin, Minnesota, United States and Canadian Geological Surveys, in the Journal of Geology, in the Bulletin of the Geological Society of America, Proceedings of the Michigan Academy of Science, Science, and the Michigan Miner. Among the names of those who have been actively working may be mentioned Frank Leverett, Frank B. Taylor, J. W. Spencer. T. C. Chamberlin, R. D. Salisbury, W. F. Cooper, J. W. Goldthwait, W. M. Gregory, A. C. Lawson, C. D. Lawton, W. H. Sherzer, M. S. W. Jefferson, C. A. Davis, and J. Harlan Bretz. One can not forbear to single out from the older names cited by Leverett the names of the Winchells among those who had given thought and study to surface geology.

The study of the surface geology and the soils is intimately connected. The United States Department of Agriculture, Bureau of Soils, under Milton Whitney, have prepared soil maps of certain areas in the State, to wit: Owosso, Allegan, Alma, Munising, Pontiac, Saginaw and Cass, which can be obtained from the department, and other notes on soils will be found in the reports of the Upper Peninsula Experiment Station and the reports by Prof. C. D. Smith.

IMPORTANCE OF SURFACE GEOLOGY.

While the deeper geology of Michigan, implying as it does a study of salt, coal, oil, gypsum, copper and iron, is of great importance, the importance of the knowledge of surface geology may be estimated when we consider its relation to agriculture, to the clay industries, to the development of peat and cement factories. All these depend largely for their material upon surface deposits. Road materials are also largely surface deposits. And the study of such deposits, their origin, extent, and the way they occur, is the field of surface geology. But besides this, questions of water supply, the kind of material to be met in railroad cuts, canals, tunnels and foundations for dams, and other engineering works, all depend for their satisfactory solution upon knowledge of the surface geology.

PRE-GLACIAL HISTORY.

The deposits of Michigan are separated into two classes by a very sharp line, which corresponds to a very long interval of time during which the State was eroded. Geological history has been divided into four great divisions, the Archeozoic, Paleozoic, Mesozoic, and Cenozoic. During the first two of these periods the harder rocks, including those which contain copper, iron and coal were laid down. They are the bony frame work, so to speak, of the two hand-like peninsulas of which Michigan is composed. The oldest of these rocks are found somewhere northwest of Marquette. This may be called the negative pole of the state, from which the hard rocks dip. The positive pole would then be the Saginaw Valley, towards which the rocks dip in every direction, under which the beds lie like a pile of saucers decreasing in size to the middle. This might be considered the hollow of the palm of the Lower Peninsula. But after these rocks were formed the State appears to have been above sea level, and the rocks cut and worn into hills and valleys (Plate VI) by streams, the general aspect of the country being perhaps much as Arkansas or Tennessee at the present date. This seems to have been the condition during the whole of Mesozoic and all but the extreme end of Cenozoic time. The elevation which carried the State above water seems to have carried it to a higher elevation than at present, for we find caves, river valleys and channels in the ancient rock surface which go quite below sea level. The most important of these valleys in the rock surface seems to have passed west from Saginaw, past Alma, and then turned somewhat northward and to have passed beyond our tracing beneath Lake Michigan somewhere between Manistee and Ludington, where the bed rock surface is beneath sea level.

ADVANCE AND CAUSE OF THE ICE AGE.

As long as elevation continued erosion naturally also would continue. But at the close of the Tertiary a great ice sheet overspread Michigan (Fig. 4) coming from centers lying at first northward from the west of Hudson's Bay and then from east of Hudson's Bay. This sheet of ice was what is known as a continental glacier, such as now buries Greenland. Other glaciers are found in Alaska, the Rocky mountains, especially the Canadian Rockies and in Switzerland. As to the fact of this great ice sheet overspreading a good part of North America (see figure 4) geologists are now entirely agreed. There is no such agreement as to the cause, and a discussion of possible causes will be found |in Chamberlin & Salisbury's recent Geology. A number of causes may have helped to produce the ice sheet, and once started there are a number of causes which would tend to make it grow. In the first place a greater height of land would promote precipitation as snow rather than rain, and the minute the snow fall, which even now often lingers in the Huron mountains until the first of June, lingered so as to accumulate from year to year we have conditions for steady growth of the ice sheet. After once the surface of the country is covered by white snow throughout the year there will be so much more heat reflected that the mean annual temperature will be much lower. At the time of the ice age in Michigan there seem to have been large lakes out west, and anything which would tend to increase the amount of snow fall in the winter would tend to promote the ice age. As the ice age seems to have extended widely over the world, and there were great ice sheets in Europe at about the same time as America, it is almost certain, however, that no mere local conditions contributed to bring about the ice age. One may imagine that the sun gave out less heat. It is even more probable that the capacity of the atmosphere to retain the heat has varied greatly from time to time. The air has a power of acting like a mouse trap in letting the heat from the sun in, as visible or radient heat, but checking its outgo. In this last respect it varies very greatly from time to time. A clear, dry air, free from carbon dioxide lets the heat escape back again very freely, as it does when we have the frosts of a clear cold night. On the other hand by building fires we check this escape, not to any appreciable extent by the heat given out by

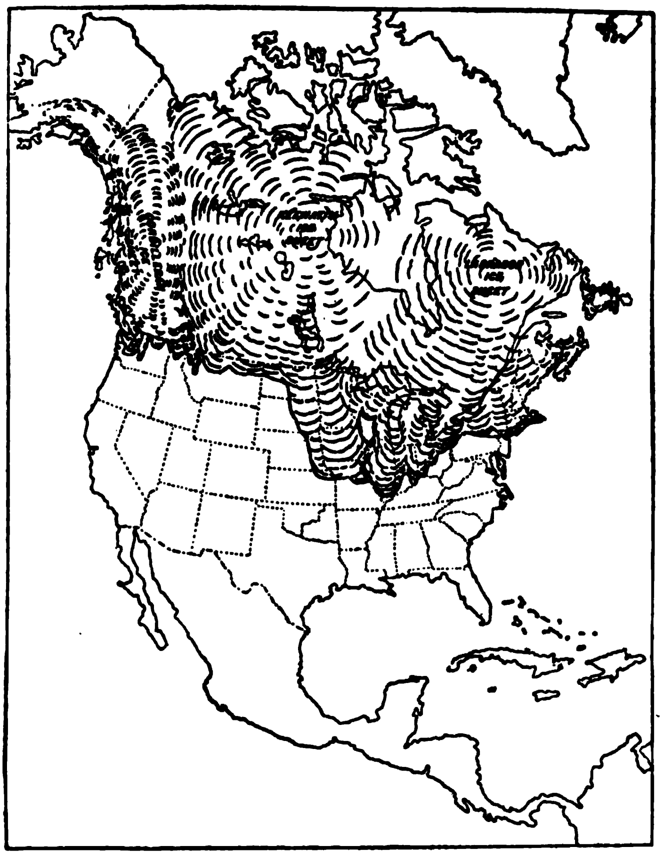

Fig. 4—Sketch map. Extent to which the ice sheet covered North America, after Chamberlin & Salisbury's Geology.

the fire, but rather by the carbon dioxide, vapor of water and smoke which are thus introduced into the air and act as a blanket. Now if by any cycle of geologic activity carbon dioxide were taken away from the air it would tend to promote the ice age as a clear night promotes frost, and this is perhaps, as Chamberlin suggests, the cause of the oncoming of the ice. It is worth noting, that if the ocean were colder it could and would absorb much more carbon dioxide than it does at present. Great increase in vegetable life also tends to abstract carbon dioxide, as do those plants like Chara, and animals like corals, which deposit carbonate of lime.

Changes in the relation of the earth's orbit to the sun have also been appealed to. Sometimes the earth's orbit is more nearly circular than at others. At present the northern hemisphere has its winter when its pole is turned away from the sun at the time the earth is nearest the sun. In some 10,000 years or so the earth will be nearest the sun in the summer of the northern hemisphere, and an attempt has been made to connect the ice ages with these astronomical changes. But even the advocates of these factors concede that the course of the ocean currents and amount of heat transferred north by the Gulf Stream, etc., must be taken into account in order to give any adequate explanation of the ice ages. When we consider the number of factors involved, *all* of which must have *some* effect, and when we consider what a difference an earthquake or the building of a coral reef which should appreciably narrow the Gulf Stream might have on the climate of Europe, and what a similar disturbance of the Japan Current might do in the Pacific Ocean, we shall, I think, find it wise not to teach too positively the exact combination of causes which produce an ice age. It is well, however, to get two or three things in mind. The climate need not have been severely cold. Such extreme cold regions as Siberia, where the ground is frozen for many feet are not covered with glaciers. These on the other hand extend down the Swiss valleys into a relatively mild climate. What is required is a great precipitation of snow. In the second place, before the ice age the country was higher than at present. When the ice came upon it, it was depressed. As soon as the ice left it felt the relief and started rising again. The causes for the apparent depression of the land beneath the ice are not simple. The center of gravity of the whole earth must have been displaced toward the ice, but the effect must have been very slight. If the ice front rose like a wall or cliff the direct attraction would be not inconsiderable so that a line of levels would rise toward the ice, and the country measured by such a line of levels would appear to be lower. But certainly the direct compressive effect of such masses of ice upon the rocks beneath, measured clear to the center of the earth would be quite noticeable. If the atmosphere were doubled, R. S. Woodward writes me, the effect would be to shorten the radius of the solid earth about two meters, say 6½ feet. This would mean an extra pressure of about 14½ pounds per square inch, or about 30 feet of water. Thus the shortening of the earth's radius would be something like 1-5 of the extra thickness imposed if it were a sheet of water, and so a sheet of ice 1,000 feet thick all over the world would shorten the radius some 200 feet. This will not be true of a limited ice sheet, but of ice sheets several thousand square miles in extent, such as the ice sheet we are now considering, it is likely that the resistance to bending of the rocks around the margin when that amount of bending was only a foot or so a mile would not be a very great factor in keeping up the crust above the point to which it would be compressed by the ice cap as above figured. Moreover if there is a viscous fluid layer anywhere not far down in the earth which can not remain at rest under a state of strain,* then it would begin to move under the extra weight of the ice cap and not come to rest until the crust beneath the ice had sunk down into this viscous fluid layer so that the buoyancy was enough to counterbalance the weight of the ice. If, for instance, the weight per cubic foot of this viscous fluid layer beneath the crust of the earth was three times that of the ice, 1,000 feet of ice would mean a depression of something like 330 feet as a limit.

Then when the ice sheet was removed these effects would be reversed, only it must be noticed that the shifting of gravity and the elastic relief of compression will follow almost immediately after the removal of the ice,† but the uplift due to the buoyancy of the viscous fluid layer now not entirely counterbalanced by the weight of the ice will take place much more slowly.

EFFECTS OF THE ICE ADVANCE.

So much for the general attitude of the land during the ice age. As the ice advanced it swept over the surface removing more or less of, and mixing up the previously existing soils, tearing off or plucking the sharp and loose ledges and reducing the form of the bed rock surface to one of smooth round outlines and curves of least resistance. Outcrops of rocks which had thus been smoothed by the ice have been likened to sheeps backs, and to the curves of a canoe turned bottom side upwards (Plate VII.) Besides this the ice did considerable cutting in the hard rock. Just how much is a serious question. Where the limestone, or sandstone or other hard cap was left as a table land on top of a hill of soft shale the ice seems to have in many cases pushed it clear off. This seems to be the explanation of those huge masses of limestone which Winchell has described,‡ in which limestone quarries have been actually started. Moreover, when we find a fresh surface newly exposed since it was beneath the ice we find it covered with lines, or striæ as they are called, which may vary in size from fine hair lines to considerable grooves (Plate VII A). These have been scratched on the rock by the ice passing over it, or more properly perhaps by the sand and stones held in the ice. Now every such scratch means the removal of a little rock flour, and the results of this removal we have in the clays laid down under the ice or in pools in front of it—our glacial clays. It is said that 60% of the mixed material thus found comes from within a few miles. The average thickness of the glacial material scattered over Michigan has been computed by Cooper§ as about 300 feet. If this be so then perhaps an average of something like 180 feet may have been removed by glacial erosion. A good part of the balance certainly has come from across the lake in Canada, where there is very much less drift and the rocks are nearly bare, while on the other hand we find numerous varieties of Canadian rocks in this state. On the other hand something should be added for Michigan material carried farther south, but it must not be forgotten that this thickness represents not merely the matter removed from fresh rock, but also all soil and decayed rock which may have been there before. Still the limestone flour which makes up 25% of our clays is not soil or decayed rock, but the direct effect of glacial erosion.

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*At about 30km. according to Prof. Wiechert, Science (1908), 27, p. 76.

†There may also be permanent compression, and set, as well as elastic.

‡Proc. A. A. A. S., 1875, 24, p. B 36.

§Ninth Report Michigan Academy of Science, p. 140.

DEPOSITS OF THE ICE AGE.

The various deposits of the ice age including those both directly and indirectly due to the ice have been quite elaborately classified by Prof. T. C. Chamberlin. A summary prepared by him for the International Congress of Geologists at Washington in 1891 is given below, but we have for our present purposes omitted those which either do not occur or have not been recognized as important in Michigan, and we may simplify this classification somewhat as follows:

1. *Material produced by direct action of the ice.*

This is characteristically unassorted so that in the same handful of clay, sand and gravel may be mixed. The resultant soil will be sandy gravelly loam. At the same time the mixture is not perfect, and the general grade depends a good deal upon the kind of rock from which the ice derived its material. If, for instance, it has been passing over sand rock there will be a large proportion of sand and little or no clay, and if on the other hand it has been passing over soft shale deposits there will be a great deal of clay derived from the shale and comparatively little coarse material. All this material is grouped together as till, or as it is sometimes called, boulder clay, or as well drillers have called it, hardpan.

(a) *Moraines.*

When this is piled up or carved into smooth hills of lenticular shape whose curves are lines of least resistance, such hills are called drumlins. Some authors would confine the use of the term drumlin only to hills which have been built up, and not those which have been carved in drumlin shape, but Prof. Russell in our reports for 1904 and 1906 applies the term to hills which he thinks have been carved into their lenticular shape (Plate VII B). Mr. Leverett thinks that the evidence is clear that some of the Traverse Bay drumlins have been built up layer by layer. In a good many cases it may be difficult, and from the shape alone impossible, to tell what is the true origin of such smooth, till covered hills.

At the margin of the ice there is a great accumulation of material borne on top of, or within them, to be deposited at the margin or let down by their melting. When this makes a well defined belt it is known as terminal moraine. When the ice projects out into a long finger, the moraines at the margin are known as lateral moraines. When two such fingers or lobes project close together so as to mingle their moraines, the combination is often known as interlobate moraine.

Very commonly these ridges are not due simply to the dumping, but the front of the ice has actually pushed the material up into irregular ridges. On the other hand when the water was ponded in front of the ice or a strong current swept along it, the waterlaid moraine may be reduced to a simple line of boulders—a so-called boulder belt.

(b) *Till plain.*

The till that is laid down beneath the ice in a smooth shape or slightly undulating is known as till plain.

2. *By ice and water combined.*

A much greater variety of formations are produced by the combined action of the ice and the waters running in, on, or through it. In fact it is doubtful if these can ever be wholly separated. Many hills which should be classed as till will show in well sections streaks of waterlaid sands or clays, and it is not uncommon to find the covering of unassorted material derived directly from the ice lying as a veneer on top of assorted waterlaid material.

This shows that the ice at that place had readvanced upon the waterlaid material without plowing it up.

a. *Eskers.*

The well known Indian ridges or hogsbacks, of coarse, sandy, not very well rounded gravel, which occur in very many parts of the state are characteristic products of streams in, on, or under the ice, which cut deep canyons or tunnels and then filled them in with gravel. These were confined in walls of ice, which finally melted away, letting the gravel fall down to right and left at as steep an angle as it can repose. These eskers, while they wind like any river valley generally run more or less at right angles to the direction of the ice motion. There is, for instance, a well marked one running from Lansing past Mason to Jackson nearly north and south, while the ice front stood nearly east and west. There is another near Lima on the electric line from Jackson to Detroit, another in Sanilac county, and near Spalding in the Upper Peninsula.

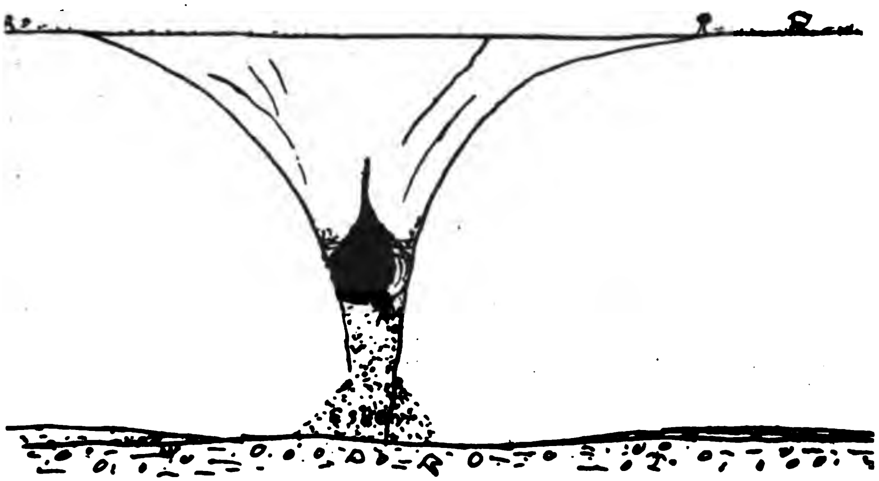

Fig. 5—Illustrating formation of eskers and bordering swamps. The debris from the top of the ice slides down towards the entrance of the cave where the esker is formed and yields less to the ground moraine each side at s–s.

b. *Kames.*

At the margins of the ice, especially at re-entrant angles in the ice front, there are often irregular heapings of assorted drift. These sometimes make the highest points of the surrounding country. The State Tuberculosis Hospital near Howell is on such a hill. They are closely associated with re-entrant angles in the front of the ice and regular terminal moraines of till. On the other hand they may often seem to represent the widening and enlargement of eskers when the ice stood for a long time with its front at a given point, and be really distributed esker deltas. A characteristic feature of glacial deposits, both of moraines and of these kames, is the presence of undrained hollows, or other hollows which have no surface line of drainage. This is due in many cases to the irregular heaping up of the material.

c. *Outwash aprons.*

Just outside the ice front there is a general accumulation of overwash apron, as it is called, which may be made up of material of any fineness—

gravel, sand, or silt—but is generally coarse and slopes gently away from the old ice front.

In these pitted gravel plains there are the same undrained hollows, but they are probably due to another cause, namely, the presence in the original gravel plain when laid down of huge masses of ice, remnants of the waning ice sheet covered by dirt and protected from the melting action and preserved,[*] while the gravel plain was left around them. Then later they melted out, leaving the pitted gravel plain, which is one of the characteristic features of the accumulation of gravel, just outside the ice front.

3. *Formation produced by water of the melting ice after its issue from the ice sheet.*

(a) *Glacial rock flour.*

In some cases the melting water from the ice was able to run away directly. In that case it could make mighty rivers whose channels would be lined with sand and gravel, taking their origin at the margin of or beneath the ice. This has been known as valley drift extending at the terminal moraine. Where these streams were very broad and large with comparatively small grade thick deposits of fine material differing from clay in one respect, that it contains a great variety of minerals and really should be called rock flour, may be formed. At the same time this rock flour may be as plastic as any clay, and many of our Michigan clays are of this type.

(b) *Gravels.*

In Michigan especially, however, the ice sheet was often margined by lakes in which were deposits of this general clay type. There are also the lake shore line gravels, the so-called "lake ridges," which are often important sources of road material, to be considered. These lakes in turn had outlets, and the streams draining them would give much the same deposits as the streams directly over the ice, only somewhat less turbid with rock flour.

WALLED LAKES.

So far as we at present know the salt ocean never reached the region of Michigan, and that class of deposit need not be considered. But not only were there, unquestionably, ice bergs in these old lakes, from the ice front, but the lakes were frozen themselves in the winter, and so in the midst of lake clays we are liable to have occasional stones, though their general bedded character is quite different from that of the boulder clay. Moreover, around the edges of the lakes ridges are pushed up and boulders worked to the shore, as they are at the present day, forming the so-called walled lakes. The interesting stone wall in Sanilac county is a relic of such a former walled lake, and in many places a fairly continuous line of boulders marks the former shore line.[†]

As these walled lakes attract considerable local interest, and often call forth fanciful explanations, it may be well to say a few words regarding them and their cause. Rather than use my own words I will translate the interesting early description given by H. Credner in 1870.[‡]

"Many lakes of Michigan, Wisconsin and Iowa, and probably also Canada, are surrounded, if they are shallow, with gently shelving shores, with a regular wall of boulders more or less frequently broken by gaps.

"The walls follow exactly the contours of the basin, and may reach a height of as much as 8 or 10 feet. They consist of sand, pebbles and boulders a

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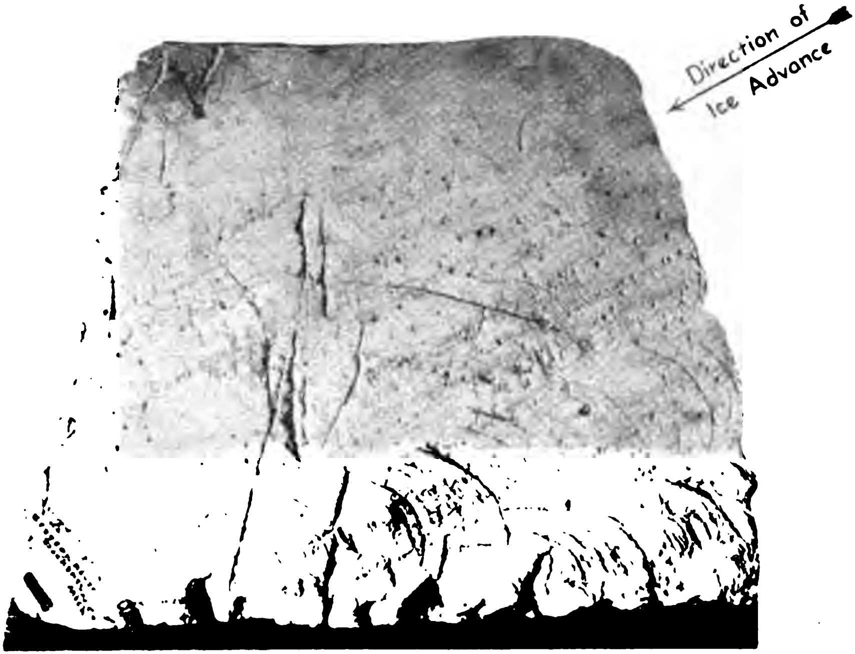
[*] Ice buried and protected from the direct rays of the sun may last for years.

[†] See Volume VII, Part 3, Plate IV.

[‡] Zeitschrift ges. Naturwiss. (1870) 35, p. 30.



A. STRIATED QUARTZITE WITH CRESCENTIC CRACKS.

B. DRUMLIN.

foot or more in size, of granite, porphery, diorite, quartzite, etc. In many places there are only piles of these latter. Such walls have an even crest, and from this slope off on both sides toward the lake and toward the land.

"By their uniform course on the strand side of the lakes, their height which may be uniform for long stretches, and accordingly their summits almost exactly level, they may give the impression that they are artificial constructions. For such they are often enough taken by the hunters frequenting those districts for beaver and otter.

"I found all these peculiarities of these walls surprisingly plainly marked in one place particularly, to wit, Lake Antoine.

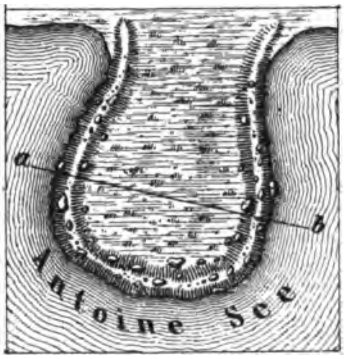


Figure 6—Boulder wall around a spit in Lake Antoine, after H. Credner.

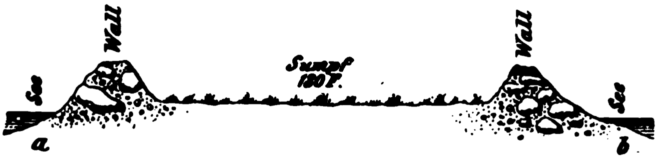


Figure 7—Cross section of the same boulder wall, after H. Credner.

"Lake Antoine spreads its expanse in the middle of the Wilderness which covers the Upper Peninsula of Michigan, some miles east of the Menominee river, in a depression between two chains of hills some hundreds of feet high. The geologic foundation of the region is formed by Huronian quartzites, limestones, iron bearing rocks and chloritic schists, is however mainly heavily covered with sand and boulders of the drift. Only here and there do outcrops of the hard rocks appear.*

"From the low flat north shore of Lake Antoine a tongue of land only a few feet above the water level runs out into the lake.

"Upon approaching the same the temptation is strong to consider it an old Indian fortification. Its outlines are determined by a fine horseshoe formed boulder wall, closed toward the lake, open toward the land. Near the shore it is only a few feet high, but increases in height the farther away it gets, up to eight feet, the maximum which it reaches in the crescent shaped bend just mentioned. Its slope toward the lake is about 40°, toward the tongue of land within about 50°. On the crest is an almost exactly flat surface on an average three feet broad. It is made up of sand, pebbles, cobbles and erratic blocks up to three feet across.

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*Herrm. Credner, die Vorsilurischen Gebilde der Ob. Hab. v. Michigan. Zeitschr. Deutsch Geol. Gesell. XXI, p. 516.

"The last are not confined to the lower part of the wall. They often form its highest points.

"This wall encloses a level, swampy piece of ground whose level is only ½ to 1 foot above the lake level. Its longest diameter is 220 feet; its shortest, 180.

"The swamp enclosed as well as the top and inner slope of the wall are covered with young birches, poplars, cedars, etc.

"This horseshoe shaped wall must be regarded as a part of the girdling wall of erratics such as surrounds other lakes in more complete fashion.

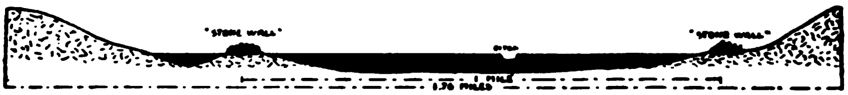

Figure 8—Cross section of boulder wall, after C. H. Gordon, Volume VII, part 3, Fig. 2.

"In answering the question how these boulder walls around many lakes come to be, three facts must be kept in mind.

1. The boulder walls are confined to lakes with flat shores.
2. They occur only in a district covered with scattered erratic boulders.
3. They belong to regions which have very cold winters.

"These circumstances indicate the following explanation of the origin of the boulder walls.

"The bottom of the lakes in this drift covered region is strewn with erratic blocks like the rest of the neighborhood. In such lakes, when they are shallow during the severe northern winter very strong ("grund eis") anchor ice forms between the pebbles at the bottom. By the ice forming between the erratics those lying near the margin of the lake, upon which the pressure works one-sidedly are shoved toward the bank, if it is flat, and little by little piled up into the shape of walls. The origin of the isolated horseshoe shaped wall above described is explained by the former existence of a shallow sandbank projecting from the steeper north bank of Lake Antoine sloping off equally in all directions, on whose flanks the shoving up of the walls took place in the fashion described.

"That these are not terminal moraines of former glaciers is shown by the fact that the walls girdle the lakes in closed circuits."

A further discussion of the walls is given by Gordon in the report of Sanilac county,* with a figure here reproduced (Fig. 8), showing the conditions for the formation of boulder walls by ice expansion. One thing that needs to be added to Credner's clear description is that it is not necessary to assume ground or anchor ice. The surface ice may have the same effect in a variety of ways.

First, during the extreme cold winter it cracks and the cracks are refilled with ice. Then as spring approaches, and in fact with every warm spell.

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*Volume VII, Part 3, p. 20.

the whole mass of ice approaches the melting point, and expanding exercises a powerful shove and thrust on the sides, evidences of which are often seen. Any boulders whose tops project near enough to the water level to be fastened to the ice, which may be several feet thick, will be affected by this.

Secondly, during the extreme cold season the level of the lakes is low. It rises with the melting of snow in the spring and boulders frozen in the ice may be buoyed up by it and moved toward the shore.

BOULDERS.

A word may well be given to the boulders themselves. These are popularly known as hard heads, field stone, and the like. They have some value themselves, and it is worth something to get rid of them from the farm. They are used very commonly for underpinning, but rarely for stone walls such as are so characteristic of New England. They often command a price of something like $4.00 per cord. Many very handsome buildings have been constructed from them. The lower story of the new medical building at Ann Arbor and the Baptist Church in Lansing are good illustrations of buildings made from these boulders. Their origin has often excited local interest. In many cases their peculiar character is such that we can almost beyond question tell from what region they came. For instance, there is a peculiar conglomerate of white sand with bright bits of red jasper which strikes the eye almost at once and is widely scattered throughout the drift of Michigan, especially that ice which came through or across Saginaw Valley. A rock precisely like this is found in what is known as the original Huronian area which lies near Thessalon, east of the "Soo" and north of Georgian Bay, and there can be but little doubt that these pebbles were largely derived from that region. There was a singular rock with eye-shaped or orbicular balls in it discovered by H. P. Parmelee of Charlevoix and figured by J. F. Kemp, whose original resting place, however, we do not know. This is not surprising since among all these hard heads of boulders there is a very great variety. Prof. Alexander Winchell collected at Ann Arbor specimens of over 100 distinct varieties of rock. In fact probably samples of every rock to be found in Canada between Lake Huron and Labrador could be found among these boulders. This would indicate of course the Nipissing mining district, and samples of considerable value in themselves, of lead, iron, gold, and other ores, and mica and other valuable substances have been sent into this office for determination. Such samples are, however, of no more worth than the sample itself. They are no sign of paying accumulations in the same region of anything similar.

Very frequently these boulders have very queer shapes and as such have attracted the admiration of residents and are set up around houses. It is easy to see that no ordinary process of rolling or battering could ever get the rocks into such shapes and a little careful study will show that the projecting ridges which tie together these grotesque shapes are veins of quartz or some other material chemically more resistant than the rock as a whole, and that the shape of the boulders is due to chemical corrosion. Anyone who will study parts of the northern country which are so lightly glaciated that the original weathered surface still remains—this is true of a part of Mt. Homer in the Huron Mountains*—will readily recognize the origin of these pebbles. The same grotesque, deeply pitted surface bound together by harder projecting lines, like the veins of one's hands, is characteristic of many of the weathered non-glaciated outcrops north. These freak boulders then represent the remnants of the old, chemically corroded surface of the rocks which have been plucked and torn away by the ice, but not shaped by it. When boulders are shaped by ice or by currents of water in or under it, they are rounded and more or less smooth but scratched. Illustrations of boulders will be found in the annual report for 1905, Plate XV; the annual report for 1906, Plate VII, and the Monroe county report, Volume VII, part 1, Figure 1. This is no definite limit known to the size of these boulders. The one figured from Monroe county is 20 x 4 feet. An equally large one is found near Swan Creek in Saginaw county, Sec. 31, T. 18 N., R. 3 W., and as we have said, limestone quarries have been opened in some of the larger limestone slabs, which seem, however, to have been, in some cases, simply the displaced table land cappings to hills of soft shale outlying and fringing the main exposures of limestone.

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*See also C. A. Davis, Ninth Report Michigan Academy of Science.

Besides the use of boulders or field stone for building, especially for underpinning, they have also been crushed for road metal, for which they are excellent if not too many limestone pebbles are included. Large ones have also been used for monuments.

RECENT DEPOSITS.

We have of course also to consider the deposits now forming; the gravels and sands along the shore—the clays deposited along the deeper water, or in the case of the St. Clair river carried down from Lake Huron and deposited in the delta of St. Clair flats. We have deposits of bog lime or marl in many of our lakes,* which have been of much importance in cement manufacture. We have also deposits of peat more fully described in a special report on that subject by Prof. C. A. Davis.†

It is well to remember that all these deposits are associated not merely with the present lakes and rivers but may also be associated with higher water levels either of the Great Lakes system or of other lakes which have shrunken or disappeared with the passing away of the great ice age.

LAKE DEPOSITS.

It will be shown that the east side of the Lower Peninsula up to an elevation of 200 feet and more above the lake has been washed by the glacial lakes, while on the west side the same belt is much narrower, being only from 100 feet above the lake down. It is worth while to consider the characteristics of these soils.

These glacial lakes were muddy with a very slowly settling rock flour, which would be called clay in fineness and plasticity, but is not at all kaolin. In fact it corresponds more to the dictionary, not the factory, definition of marl. Usually about a quarter is dissolved by acids and may be classed as a limestone or dolomite flour‡. There is also a large amount of finely divided quartz and feldspar and other minerals. Every once in a while in these glacial clays a big stone or pebble may be dumped from the melting of an ice cake. But very often they are quite free from any coarse grit, and very well bedded in thin layers.

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*Volume VIII, Part III.

†Annual report for 1906.

‡Annual report, 1903, pp. 184–188. Also Vol. VIII, Part I.

POLISHING POWDER.

Even when free from coarse grit these glacial clays always contain, however, a large proportion of sharp fine particles, so that they may be used for brass polishing. As the water level dropped it was in shallow water for a longer or shorter time, and then coarser, sandier deposits accumulated. These are sometimes quite thick, but in general it is characteristic of the old lake bottoms that they have stiff clays overlain by more sandy clays, and sands which may very often be shallow. Throughout the whole lake bottom region the sands will rarely be so deep that trees or alfalfa can not get near enough to the bottom to get water, and very many excellent orchard sites are found on the old sand ridges.

These lake clays are often brick clays. But owing to the amount of lime they will not generally burn hard or very red. They are white to light orange or buff.

The lime has, however, often been leached out of the upper few feet, which then makes a redder brick.

While they may be of value for pottery, brick and tiles, experience so far goes to show that they are *not fit for* making Portland cement. For this purpose there must be a uniformity in composition with low magnesia, which they do not possess. Nor will they generally make face, front, or paving brick.

ROAD GRAVELS.

The road gravels are the old beach lines, especially the very highest lake borders, where they cut and concentrate the gravel from stony till, and the overwash gravels, kames, eskers and valley trains connected with the ice front. These gravels deposited in powerful swift flowing streams in or from the ice are on the whole the best, and are deposited in almost all parts of the state. In all our gravels there is enough binder.

The great channel that comes down by Mecosta, that around Grand Rapids, the upper valley of the Cass, the esker that runs from Mt. Hope cemetery, Lansing, south, are but conspicuous examples. The Tecumseh gravel is shipped clear to Central Ohio. The U. S. Department of Agriculture have furnished us copies of their soil maps on which gravel pits are indicated. The Miami gravel is the prevailing formation.

BOG LIME.

Bog lime or Marl, shell marl as it is often called, is fully described in our especial report on it.*

With all the lime in the clays that we have mentioned it is no wonder that the waters of Lower Michigan, especially the spring waters, are hard. In fact it may almost be said that they are normally saturated with bicarbonate of lime or its equivalent. That would mean .238 ounces $CaCO_3$ per cubic foot of water.

Where this water is exposed to air and sunshine whether in lakes or standpipes it is rapidly decomposed and the carbonate of lime thrown out. Shell producing animals do a small part of the work, but by far the greatest part of the work is done by lowly lake weeds, especially vine-like forms of the Chara family. Others like Schizothrix take part. But this latter makes more or less firm coatings with a fibrous cross fracture over bits of stick and dead shell, and makes the pebble-like bodies known as marl biscuit. The soft white or blue slime which fills some of our lakes to a depth of very many feet is the Chara-lime as Davis has shown. Probably one-third of the 5,000 or more lakes of Michigan have more or less bog lime, and there are very many bogs which were once lakes that have been filled with it.

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*Volume VIII, Part 3.

It is often covered over with peat. It is most frequent:

In the upper chains of lakes.

In spring fed lakes with cold water.

In lakes of the higher parts of the state in the morainal regions.

PEAT.

This has also received special treatment.* In the broadest sense it includes all accumulations of nearly pure vegetable matter. Muck is not so pure. Davis distinguishes a number of classes according to their origin. But, since the higher and southern parts of the state have been longest exposed, there has been the greatest length of time for the accumulation and decomposition of peat deposits there. Moreover there are the divides where the drainage is most uncertain. There too are the old glacial dumping grounds and the abandoned channels of the waters draining them.

This then is the region of our greater deposits of peat. Some peat is also found back of the old beach ridges especially the very highest ones, and those of Algonquin and Nipissing time. It very commonly fills up small lakes and may build out over deposits of Chara bog lime. The oldest, blackest, and most decomposed is in the south part of the state along the old glacial drainage channel system from Niles northeast toward the Thumb (Figures 10–12).

RIVER SILTS.

Most Michigan rivers overflow their banks—of late years more than ever. In certain cases, and particularly in Saginaw county around Shiawassee Lake, miles and miles of country are naturally thus covered.

When the muddy waters of the swollen streams thus spread over their flood plains a deposit of mud takes place which is heaviest and coarsest near the main channel, finer and lighter at the margin. Thus the flood plains are built up and are normally somewhat higher next the stream. Along the margins of the flood plains next the bluffs is likely to be a swampy belt.

These flood plains are well stratified, but in irregular layers. We do not find the enormously thick beds without apparent break which are so characteristic of the glacial clays. They are generally very fertile, and their fertility is ever renewed.

Of the same general character but liable to be coarser are the deltas which form where any stream suddenly widens into a lake. The greatest of these is the St. Clair flats, described by Cole.†

CONNECTION OF SURFACE DEPOSITS AND SOILS.

It is obvious that there is a close connection between the various kinds of surface deposits and soils. Dune sand is a kind of soil, and at the same time a particular kind of deposit. The fact is a classification of soils and surface deposits deal with the same material but from a different point of view. The surface geologist is studying them in the first place to see how they came to be, the soil expert to see what they are good for agriculturally.

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*By C. A. Davis, annual report for 1906.

†Volume IX, Part 1.

But if there is any difference in two soils there must have been some difference in their origin and hence the surface geologist, if he has an economic factor in view, can always make some distinction between soils which would be separated by a student of soils simply from the view of the Department of Agriculture. The geologist has also other uses in view. On the other hand some knowledge of how the soils were formed would be of the very greatest assistance in mapping different kinds and helping one to look out for important factors. Two soils of equal fineness may both pass for clay, but if one were a very fine rock flour with a great variety in chemical composition, while the other was almost entirely hydro-silicate of alumina, the agricultural value of the same, I think, would be very different. While all of the factors could be found out by sufficient detailed chemical and physical investigations, yet one can not analyze every foot, and there is often great need in soil mapping of knowing the geologic history.

TYPES OF MICHIGAN SOILS.

The United States Department of Agriculture have so far mapped the following soil areas, which are sufficient to give us a fair idea of the types of the soils in the Lower Peninsula, though an area in the Grand Traverse region is urgently needed, and one to give us some clue to the soils of the western part of the Upper Peninsula, and thus there are still important types of soils which they have not touched. The areas mapped are mentioned on p. 9. The following descriptions of their soils are taken from the United States soil survey field book. It will be noticed that the most important factor in their classification is the relative proportion of grains of different fineness in the soil and subsoil. There are a few types to which no locality name is given. These are as follows:

"*Dune sand.*

"The dune sand consists of loose, incoherent sand forming hillocks, rounded hills, or ridges of various heights. The dunes are found along the shores of lakes, rivers or oceans and in desert areas. They are usually of no agricultural value on account of their irregular surface, the loose, open nature of the material, and its consequent low water-holding capacity. The dunes are frequently unstable and drift from place to place. The control of these sands by wind-breaks and binding grasses is frequently necessary for the protection of adjoining agricultural lands. In certain regions, where levelled and placed under irrigation, the dune sand is adapted to the production of truck crops and small fruits."

The dune sands occur around the edges of the present lakes and also along the lines where the lakes formerly existed. They are nearly pure silica, and the softest waters in the state have been obtained from them. In fact, near East Olive, the excessive softness of the water is supposed to have something to do with a hoof disease. The sand is also shipped from Port Crescent in Huron county for furnace linings. There is, however, quite a little difference in the sharpness of the dune sands in the different regions. The longer it has been handled of course the more rounded it gets, and in many cases it is derived from sands already rounded.

Muck, Peat and Meadow.

The term muck as used by the Department of Agriculture is practically the same as peat, being, however, applied to the more decomposed varieties, such as are found for instance around Kalamazoo, and are used very extensively in this state to grow celery, peppermint, etc. It occurs in the more extensive swamp areas especially those south of Saginaw Bay. Further north the material will be more commonly classed by them as peat. In the maps, Plate XII, by Mr. Nellist this variety of soil is not especially indicated except by the swamp symbol. It may overlie to a varying depth any of the other soils. It is particularly likely to overlie also what is known as marl or bog lime, which occasionally occurs in this state in what might be called a formation by itself as described below. The peat overlying bog lime is not so likely to be sour, whereas many other peats contain sulphate or other organic salts of iron, and in that case are very likely to be sour. Such beds are very likely to be underlain by hardpan of quite a different nature from the till to which the term is also applied. This hardpan is cemented together by iron, and may pass gradually into deposits of bog iron ore, which may also contain considerable quantities of manganese. Small deposits of bog iron ore are found in various places in the state, as in Branch county, as well as in the Upper Peninsula, but are of no present commercial value. The soil book of the Department of Agriculture describes muck and meadow as given below. Meadow is generally a term applied to various kinds of bottom land.

PEAT.

"This is vegetable matter consisting of roots and fibres, moss, etc., in various stages of decomposition, occurring as turf or bog, usually in low situations, always more or less saturated with water, and representing an advanced stage of swamp with drainage partially established."

MUCK.

"This type consists of black more or less thoroughly decomposed vegetable mold, from 1 to 3 feet or more in depth and occupying low, damp places, with little or no natural drainage. Muck may be considered an advanced stage of peat brought about by the more complete decomposition of the vegetable fibre and the addition of mineral matter through decomposition from water and from æolian sources, resulting in a finer texture and closer structure. When drained, muck is very productive and is adapted to corn, potatoes, cabbage, onions, celery, peppermint and similar crops."

MEADOW.

"This term is used to designate low-lying, flat, usually poorly drained land, such as may occur in any soil type. These areas are frequently used for grass, pasturage, or forestry, and can be changed to arable land if cleared and drained. The present character of meadow is due to lack of drainage, and the term represents a condition rather than a classification according to texture. Textural variations frequently occur in meadow areas on a scale too small to permit of detailed mapping. In many areas the term "meadow" has also been used to represent small bodies of bottom land occasionally or frequently subject to overflow, which are normally placed under cultivation and constitute land of high value for the production of various general farm crops. Within these bottoms the soils vary frequently in texture, even within small areas, and on account of occasional overflow the character of the soil at any one point is subject to change. The use of this term should be avoided whenever it is possible to separate such areas into distinct soil types."

FINE SOIL DIVISIONS OF DEPARTMENT OF AGRICULTURE.

In a general map of the state it is not possible to go into the numerous fine divisions—some 20 more or less—of the soils made by the Department of Agriculture. On the map prepared by J. F. Nellist, Plate XII, are but six main divisions outlined. All the finer sandy soils are grouped together in one pattern, and they are generally overwash either from the ice directly or more or less rehandled by lake action. Then we have the gravel plains, the outwashed apron from the ice front. We have also gravel ridges, either old beach lines or eskers which are good road material; then we have the morainal soils which are generally hilly and more or less stony; then we have the till plains which occur between the moraines. Finally we have the purer clays of the old lake bottoms. Thus in one pattern (the yellow color) we have soils separated by the Department of Agriculture as Miami sand, the Miami fine sand, Saugatuck sand, the Miami gravelly sand, and the Clyde fine sandy loam. The green color of the old lake bottom covers generally a very good group of soils. The typical soil is perhaps the Clyde clay with sandy streaks or ridges, or with faint sand streaks with a small quantity of sand as Saginaw sandy loam, the Clyde sandy loam, the Clyde loam, and the Clyde silt loam. The typical soil of the gravel pattern (brown color) is perhaps the Miami gravel, but it will also include areas of Miami gravelly sand, the Miami fine sandy loam, the Miami sandy loam, and the Miami sand, the Clyde sandy loam, the Clyde sand, the Clyde gravelly sand, and Clyde stony and sandy loam, and the Marshall loam. The typical soils of the morainal areas (colored red) are the Miami clay loam, the Miami stony loam, and Miami clay, but the Plainwell stony loam, which is the same as the Miami stony sand and the Kalamazoo gravelly loam, which is the same as the Clyde gravelly sand, will also generally be included under these heads. Under the blue or till plain color the type is perhaps the Miami fine sandy loam, but almost any of the Miami series of soils can be included. These are about all the soils which have yet been determined in the lower part of the state, but the Volusia series derived from a slight reworking of the shales should unquestionably be found in the Grand Traverse region, and probably some slight representation of the Dunkirk series. In the Upper Peninsula there is at least one important soil to be added to the list. This is the Superior clay, which is the lake bottom of the former extension of Lake Superior, or possibly of a lake that existed between the ice ages. Then too in this region there will be areas which will have to be defined as rock outcrop, absolutely bare and rough and stony land where timber alone could grow. In a general way it may be said that almost all the soils of the Lower Peninsula and of the Upper Peninsula around Green Bay contain very considerable quantities of limestone rock flour.[*] In many parts of the Lower Peninsula there is a very considerable amount of gypsum, or land plaster, mixed with the soil, all of which are fertilizing ingredients of value. Even the Lake Superior sandstone, devoid of fertilizing power as it may seem in some instances runs up to as much as 7% of potash, which is, however, present in the shape of feldspar, and can only very slowly be put in shape to be available for agriculture.

With regard to these soils it should be said that the Department of Agriculture divides each general group into a series passing from coarse sandy soils to clay soils, that the Miami series which is a glacial soil has a generally light surface soil, the Marshall series is darker, while the Clyde series and the Dunkirk series have both been reworked considerably since the ice age. We copy from the soil survey field book the descriptions which apply to the various soils found in the state. They divide the grain of which the soil is composed into seven classes, and it is by the proportions of these that they divide each series into eleven classes from sand, through loam to clay, as is shown by the following table:

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[*] Analysis of clays and soils bring out the fact will be found in Volume VIII, Parts 1 and 3; also in previous annual reports, 1901, pp. 26 and 27; 1903, pp. 184–188; 1904, pp. 73, 94; 1905, pp. 393, 557, 562; 1906, pp. 73, 80.

U. S. SCHEME OF SOIL CLASSIFICATION, BASED UPON THE MECHANICAL COMPOSISION OF SOILS.

1 mm. = about 1-25 inch.

Class.	1. Fine gravel. 2–1 mm.	2. Coarse sand. 1–.5 mm.	3. Medium sand. .5–.25 mm.	4. Fine sand. .25–.1 mm.	5. Very fine sand. .1–.05 mm.	6 Silt. .05–.005 mm.	7. Clay. .005–0 mm.
Coarse sand.	More than 25% of.... 1 + 2					0–15	0–10
	More than 50% of 1 + 2 + 3.					Less than 20% of 6 + 7.	
Medium. sand.	Less than 25% of 1 + 2.					0–15	0–10
	More than 20% of 1 + 2 + 3.					Less than 20% of 6 + 7.	
Fine sand.	Less than 20% of 1 + 2 + 3.					0–15	0–10
						Less than 20% of 6 + 7.	
Sandy loam.	More than 20% of 1 + 2 + 3.					10–35	5–15
						More than 20% and less than 50% of 6 + 7.	
Fine sandy loam.	Less than 20% of 1 + 2 + 3.					10–35	5–15
						More than 20% and less than 50% of 6 + 7.	
	Will pass through 10-mesh sieve.	Will pass through 20-mesh sieve.	Will pass through 40-mesh sieve.	Will pass through 80-mesh sieve.	Will pass through 200-mesh sieve.		

Sieve tests of tills will be found in Russell's report for 1904, p. 73, and 1906, p. 80, and it will be noticed that while a fourth to a half passes through the 200-mesh sieve, a very noticeable proportion of up to 38% remain at the same time on the 50-mesh sieve, thus bringing them in the class of sandy loams.

Numerous other analyses of clays may be found in our reports* and peat and muck analyses will be found in Davis' peat report* and Livingston's report,† and the reports of the Board of Agriculture. A series of tests of sands will be found in Ries & Rosen's molding sand report, which precedes this.

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*Especially pp. 48–62 of Volume VIII, Part 1.

The following are the United States Department of Agriculture descriptions of our soils:

Clyde clay.—"The soil, from 6 to 9 inches deep, is a silty clay loam of a brown or black color. Where the proportion of organic matter is highest, the soil is darkest and more loamy and friable. The subsoil is a bluish or drab-colored clay, very tenacious and practically impervious to water. The type is derived from glacial lake deposits, and occupies low, wet, level areas, some of which were originally covered with peat. With good drainage the soil is well adapted to sugar beets, as well as to general farm crops."

Clyde fine sand.—"The soil consists of a dark-gray to black fine sand, varying in depth from 4 to 20 inches. The subsoil has about the same texture as the soil, but contains less organic matter and is lighter in color. In some instances the subsoil contains layers of peat. The surface of the type is nearly level and natural drainage is generally poor. The type has been formed by the reworking of the glacial sands and their deposition in former lakes. The soil is greatly improved by artificial drainage. The crop value of this soil depends much upon the proportion of organic matter present and its drainage conditions. It is suited to small fruits, being an ideal soil for strawberries. Fair crops of corn, oats and potatoes are produced."

Clyde fine sandy loam.—"The soil, from 9 to 12 inches, is a very fine sand loam of a brownish-gray or brown color, homogeneous in texture, friable and easily kept in good tilth. The subsoil is a brown or yellow fine sand or fine sandy loam to a depth of 2 feet or more below the surface, overlying a clay similar to the subsoil of the Clyde loam. But soil and subsoil are entirely devoid of gravel. Portions of the type seem to be the result of delta formations, subsequently modified by wind and wave action, while other portions occur in the form of low ridges as wind-blown beach deposits. The surface is slightly undulating and rolling, and drainage varies largely with local topography. Besides general·farming and dairying, sugar beets, beans and potatoes are important interests, and to a less extent, chicory, apples, grapes, pears and vegetables."

Clyde gravelly sand.—"The soil is medium-textured, light to dark brown loamy sand or light sandy loam 10 inches deep, carrying a large percentage of gravel. The subsoil is a rather coarse incoherent gravelly sand, usually grading into a mixture of coarse sand and fine gravel at a depth of from 24 to 30 inches. Clay is often found at from 4 to 8 feet below the surface. The type is generally well drained. The topography varies from gentle slopes to gently rolling ridges representing old beach lines or terraces. The soil is the result of beach or shallow water deposition, in places influenced to some extent by local wash from the higher lands. Fairly good yields of corn, oats, wheat, rye, timothy, clover, and buck wheat are secured, and some special crops, such as sugar beets, beans and potatoes are grown. The soil is also adapted to fruit and truck crops."

Clyde gravelly sandy loam.—"The soil to a depth of from 8 to 15 inches is a coarse to medium black sandy loam, rich in organic matter and containing a varying percentage of gravel. The subsoil to a depth of 36 inches

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*Annual for 1906.
†Annual for 1903.

consists of a mixture of medium to coarse sand, with a high percentage of gravel. The surface varies from nearly level to gently rolling and the drainage is good. This soil has been formed by the reworking of glacial material by water and its deposition in lakes. It is well adapted to potatoes and produces fair crops of grain, hay, onions, carrots and sugar beets."

Clyde loam.—"The soil ranges from a moderately friable loam to a rather heavy, compact loam of a dark-gray, brown, or black color, from 8 to 12 inches deep, resting upon a drab-colored sandy or silty clay somewhat streaked and mottled with iron stains. On account of former inadequate drainage much of the soil is still in a puddled and compact state, sticky and impervious when wet, and very hard when dry. This condition is emphasized by low-lying areas that have been cultivated only a short time. In its natural state the soil possesses marked clayey properties to within a few inches of the surface, where there is an accumulation of organic matter. In the better drained areas the soil is mellow, and the subsoil, too, is more friable and not pervious to water. The type is derived from glacial lake deposits that have not been modified to any extent by subsequent stream action. Its almost level surface with occasional low knolls and swells and intervening shallow depressions naturally cause poor drainage. When properly drained and cultivated, large crop yields are secured. The principal crops grown are corn, oats, wheat, hay, and sugar beets. It is considered an excellent soil for the latter crop."

Clyde sand.—"The soil consists of 12 inches of black medium to fine loamy sand, underlain by sand to a depth of 30 inches, which in turn is generally underlain by clay. The type occupies low, flat areas and is generally swampy and poorly drained. It is composed of reworked glacial sands with the addition of organic matter. When well drained the soil produces good crops of corn, wheat, grass, oats, rye, and all kinds of truck crops. It is a fair soil for sugar beets."

Clyde sandy loam.—"The soil is a dark gray or brown mixed-textured sandy loam from 8 to 12 inches deep, resting on material of similar texture, but lighter color, which is underlain at 18 inches by a drab or brownish mottled sandy clay, sometimes tending more toward a sticky sandy loam. The soil carries a fair percentage of organic matter, and is easily brought into good tilth. The type has been formed by the reworking of glacial material as beach or shallow water deposits. The surface is level to gently rolling, and upon the whole the drainage features are fairly good. This is a good soil for general farm crops, sugar beets, beans, potatoes, and orchard fruit.

Clyde silt loam.—"The soil is a light to chocolate-brown silt loam 10 inches deep, resting upon a similar silt loam of a lemon-yellow color, containing little or no organic matter. The texture is very homogeneous at a depth of three feet, and gravel is entirely absent, but there are some boulders strewn over the surface. The soil is very friable and easily kept in good tilth. The type seems to be derived from material carried by streams and deposited in the glacial lake. It is somewhat rolling in topography, and the drainage is fairly good. The soil is well adapted to grain and hay, and is used for general farm crops and for the production of chicory."

Clyde stony sandy loam.—"The soil is a dark-brown, medium textured gravelly sandy loam, 18 to 24 inches deep, underlain by a sandy loam or mottled brown clay loam containing a small amount of gravel. A noticeable characteristic is the large number of boulders strewn over the surface and occurring to a less extent below the surface. These boulders are mainly of granite, and range from cobbles to angular fragments 2 to 3 feet in diameter. With these stones removed from the surface the soil is a good friable sandy loam, and produce fairly good crops. The type is of glacial or lacustrine origin, has level or gently rolling topography, and for the most part is fairly well drained. The crops grown are corn, oats, wheat, sugar beets, beans, potatoes, hay, etc."

Marshall gravel.—"The soil is a dark brown to black sandy loam, containing a high percentage of fine gravel. At 15 to 24 inches it grades into a bed of gravel and coarse sand. With the exception of some pasturage afforded early in the season it has little agricultural value, and crops being small and easily affected by drought."

Superior clay.—"A heavy, compact, and almost impervious red clay, with no apparent difference in color or texture between soil and subsoil. When wet it is of a brick red color, and quite adhesive and gummy; when dry cracks an inch or more in width are common on the surface, and the soil breaks up into cubical blocks. Sometimes there are small fragments of rocks in both soil and subsoil, and usually upon new ground there is an inch or so of vegetable mold. The type occurs generally in broad and flat areas, with surface inclinations toward streams, and is very retentive of moisture. The soil is lacustrine in origin. It is adapted to timothy and clover. It improves with use and good crops of potatoes, peas, beets and other root crops have been grown."

Superior sandy loam.—"A gray to reddish sand or light sandy loam, of medium texture, varying in depth from 12 to 24 inches. Sometimes the surface is strewn with small rocks and boulders in such quantities as to interfere with cultivation. The subsoil is a stiff, tenacious, impervious red clay similar to the material forming the Superior clay, and it is sometimes interstratified with thin layers of fine sand. The sandy soil is the result of wash from higher lying sandy land. The type usually occupies level and gently rolling areas, with sufficient elevation to secure good natural drainage. It is a warm soil, easily tilled, and adapted to a variety of crops. The crops grown are clover, timothy, potatoes and small fruits. The original timber growth is pine."

MIAMI SERIES.

"The Miami series is one of the most important, widely distributed, and complete soil series that has been established. The series is characterized by the light color of the surface soils, by derivation from glacial material, and by being timbered either now or originally. The heavier members of the series are better adapted to wheat than the corresponding members of the Marshall series, but they do not produce as large yields of corn."

Miami stony sand.—"The soil is a loose yellow or brown sand or light sandy loam 8 inches deep, underlain by yellow sand of varying texture to a depth of three feet or more. Stones and large boulders, constituting 20 to 70 per cent of the total mass, are scattered on the surface and mixed with the soil and subsoil. The type is derived from morainac material and occupies large, rounded hills and ridges. Corn, rye and buckwheat are grown to some extent, but the yields are low."

Miami stony sandy loam.—"The soil is a gray or brown sandy or fine sandy loam from 6 to 10 inches deep, underlain by brown or yellow sandy loam or heavy sandy loam. Both soil and subsoil contain from 20 to 70 per cent of stones and gravel, consisting of granite, sandstone and limestone. The type is derived from the weathering of glacial material, occupies the rolling and level uplands, and is usually well drained. The soil is not very productive. Beans, corn, wheat and oats, and grasses are the main products. Truck and fruit do fairly well."

Miami stony loam.—"The soil consists of a gray to brown loam about 10 inches deep, underlain by a yellow loam or heavy sandy loam, which is in turn underlain locally by beds of consolidated gravel or bed rock. There is from 20 to 60 per cent of rounded and angular stones on the surface and mixed with both the soil and the subsoil. The stones vary from 1 to 8 inches in diameter. The type generally occupies large, rounded hills and table lands and gently rolling lands at lower levels. It is chiefly derived from moranic material. The soil is very productive, and produces good crops of corn, wheat, grass, oats and fruit, particularly apples. The type also affords excellent pasture."

Miami gravel.—"The soil is a medium grade sandy loam about 12 inches deep, containing 50 per cent of gravel from ½ inch to 2 inches in diameter. The subsoil consists of cross-bedded sand and gravel, the latter often coated with calcium carbonate. The type occurs only in small areas and is the outcrop of reworked glacial gravels in river cliffs. For the most part it is uncultivated and is of little value for farming."

Miami gravelly sand.—"The soil is a brown gravelly sand of medium to coarse texture, 9 to 12 inches deep, grading through a lighter brown gravelly sand into a mixture of coarse sand and fine gravel at a depth of about 3 feet. In some places the underlying gravel comes within a few inches of the surface. The type represents mainly old beach lines, and is formed by material deposited by wave or stream action. Its usually rolling or ridgy topography insures good drainage. The type is best suited to truck and fruit crops."

Miami gravelly sandy loam.—"The soil to a depth of 8 inches is generally a light brown sandy loam containing a high percentage of gravel and frequently small stones. The subsoil varies from a sticky sandy loam to a gravelly sand, and is often underlain at a depth of 2 to 3 feet by a bed of gravel. The surface is rolling and the type often occurs as rounded knolls or hills, generally composed of stratified and unstratified sands, clays and gravels. It is of glacial origin, and often represents moranic material. Where cultivated, the crop yields are only fair. It is not adapted to general farming, though fairly well adapted to light farming and the production of small fruits. In favorable localities peaches do well on this soil."

Miami gravelly loam.—"The soil is a brown or reddish loam 12 inches deep, containing 15 to 30 per cent of rounded gravel. The soil is underlain to a depth of 24 inches by a stiff, tenacious clay loam, which is in turn underlain by gravel. The type occupies level or gently rolling river terraces, and is composed of original glacial material worked over by the streams. This is recognized as fine soil for general farm purposes."

Miami sand.—"The soil is a coarse to medium loose, incoherent sand, underlain by yellow or reddish sand of about the same texture. This is the prototype of the Norfolk sand of the Atlantic coast, and Fresno sand of the Pacific coast, and is a typical truck soil. The type may be either of glacial or alluvial origin, modified by wind action, and has a level or rolling topography."

Miami fine sand.—"The soil is a fine yellow or light brown sand 6 to 12 inches deep. The subsoil consists of a fine orange or yellow sand. The type is free from stones and often occurs as dunes. It has good natural drainage and is easily tilled. The principal crops are corn, potatoes, berries, and, of less importance, wheat, oats, grasses and cabbage. The soil is best adapted to truck, potatoes and small fruit."

Miami sandy loam.—"The soil is light gray to brown sandy loam 8 to 14 inches deep, underlain by a sandy loam or sand, sometimes containing fine gravel. The type is of glacial origin and occupies level or gently rolling areas, and sometimes rounded hills with kettle like intervening depressions. In some areas the soil is adapted to corn, wheat, grass, rye and oats; in others mainly to fruits, small fruits and truck crops."

Miami fine sandy loam.—"The soil consists of a loose, loamy brown sand or sandy loam from 10 to 30 inches deep, the sand being from medium to fine in texture. The subsoil is a clay loam or sticky sand loam. This type differs from the Miami sandy loam in having the heavy subsoil within three feet of the surface. The type is of glacial origin, occupies rolling country, often occurring as rounded hills and ridges, and has good drainage. The Miami fine sandy loam is a good corn soil. Wheat yields from 15 to 30 bushels, oats from 35 to 75 bushels, rye from 15 to 30 bushels, and hay 1½ to 2 tons per acre. The soil is used for general agriculture, but is especially adapted to medium and late truck crops and fruit."

Miami loam.—"The soil consists of a light brown to dark gray rather mellow loam about 12 inches deep, sometimes becoming lighter in color with depth. The subsoil is a compact yellow sandy clay, frequently carrying stones and gravel. Often at a depth of from 14 to 25 inches gravelly material is encountered. A few boulders and pebbles usually are found on the surface. The type occupies level to rolling upland, and is fairly well drained except in some of the level areas. The soil is especially suited to corn and potatoes, while small grain and grass are grown with a fair degree of success. Small fruits, such as strawberries and raspberries, do well."

Miami silt loam.—"This is a light brown or yellow to almost white silt loam from 8 to 12 inches deep, underlain by a compact silt loam or silt clay of a yellowish color. The type occupies rolling to hilly areas and was originally timbered. Its origin is due to the deposition of loose over glacial till. The soil is not as productive as the Marshall silt loam, but produces good yields of wheat, corn, clover, and timothy hay."

Miami clay loam.—"The soil to an average depth of 10 inches consists of a yellowish gray to light brown somewhat silty loam, underlain by light brown to yellow, sometimes mottled, stiff silty clay loam or clay, which is in turn underlain by boulder clay at depths varying from 5 to 10 feet. Stones and erratic boulders are found on the surface, but in no great quantity except in small areas. The type occupies uplands and the surface is level to gently rolling, except near streams, where it becomes hilly and broken. The flat interstream areas generally require artificial drainage. The soil is fairly good for general farming, and is especially adapted to small grains and grass crops."

Miami black clay loam.—"The soil is a black clay loam 10 to 12 inches deep, underlain by a tenacious drab clay. The type is of glacial origin, is generally level, and the natural drainage is poor. When thoroughly drained this soil is very productive, particularly for corn. It is also well adapted for grass and wheat."

THE ICE RETREAT.

We have said at one time Michigan was covered by a great ice sheet moving from the north. This did not, however, move steadily out from one center until it reached its extreme size and then retired steadily backward. That is not the way glaciers do at present. A series of winters with extra snow and cool summers will push them forward, and the accumulated effect of a series of hotter years will cause them to retreat though the effect on the glacier lags some time behind the weather.* So it was with the great ice age. There are a series of advances followed by very marked retreats. This is, of course, especially conspicuous in the states to the south of us, but it seems also that the ice at times retired so far as to leave Michigan uncovered, and indeed it is quite possible that the ice entirely disappeared. Some, indeed, have supposed alternate glaciation, first in the northern hemisphere and then in the southern. The signs of these oscillations as we find them are:

1. Beds of soil or wood which have been encountered in sinking wells and shafts.
2. The difference in the hardness of the drift. The older, having been overridden by the ice, is notably more compact.
3. The difference in the direction from which it received most of its material.
4. The weathering (including the erosion, the bleaching, reddening and leaching out of the lime) of the older till deposits during the time the ice retired, which marks off the older till from the younger.
5. In a few cases, especially around Toronto, marine clays with shells have been found between the different drift sheets. The fullest list of stages of the ice age made out which will be found in Chamberlin & Salisbury's Geology, Volume III, page 383, is as follows:†

I. The sub-Aftonian, or Jerseyan, the earliest known invasion.
II. The Aftonian, the first known interglacial interval.
III. The Kansan, or second invasion now recognized, from west of Hudson's Bay.
IV. The Yarmouth, or Buchanan, the second interglacial interval.
V. The Illinoian, the third invasion, from Labrador.
VI. The Sangamon, the third interglacial interval.
VII. The Iowan, the fourth invasion, from west of Hudson's Bay and Labrador.
VIII. The Peorian, the fourth interglacial interval.
IX. The Earlier Wisconsin, the fifth invasion, from Labrador and Hudson's Bay.
X. The fifth interval of deglaciation, as yet unnamed.
XI. The Later Wisconsin, the sixth advance, from many centers, lobate.
XII. The glacio-lacustrine sub-stage.
XIII. The Champlain sub-stage (marine).

Of these stages probably not more than six can be even guessed at at present, so far as Michigan evidence is concerned. There is, however, distinct evidence of ice motion from the northwest, scattering bits of native copper toward the southeast and making striæ in that direction. Whether this is Kansan or Iowan I would not pretend to say. Probably during the interval between this and the motion of the ice from the Labrador cen-

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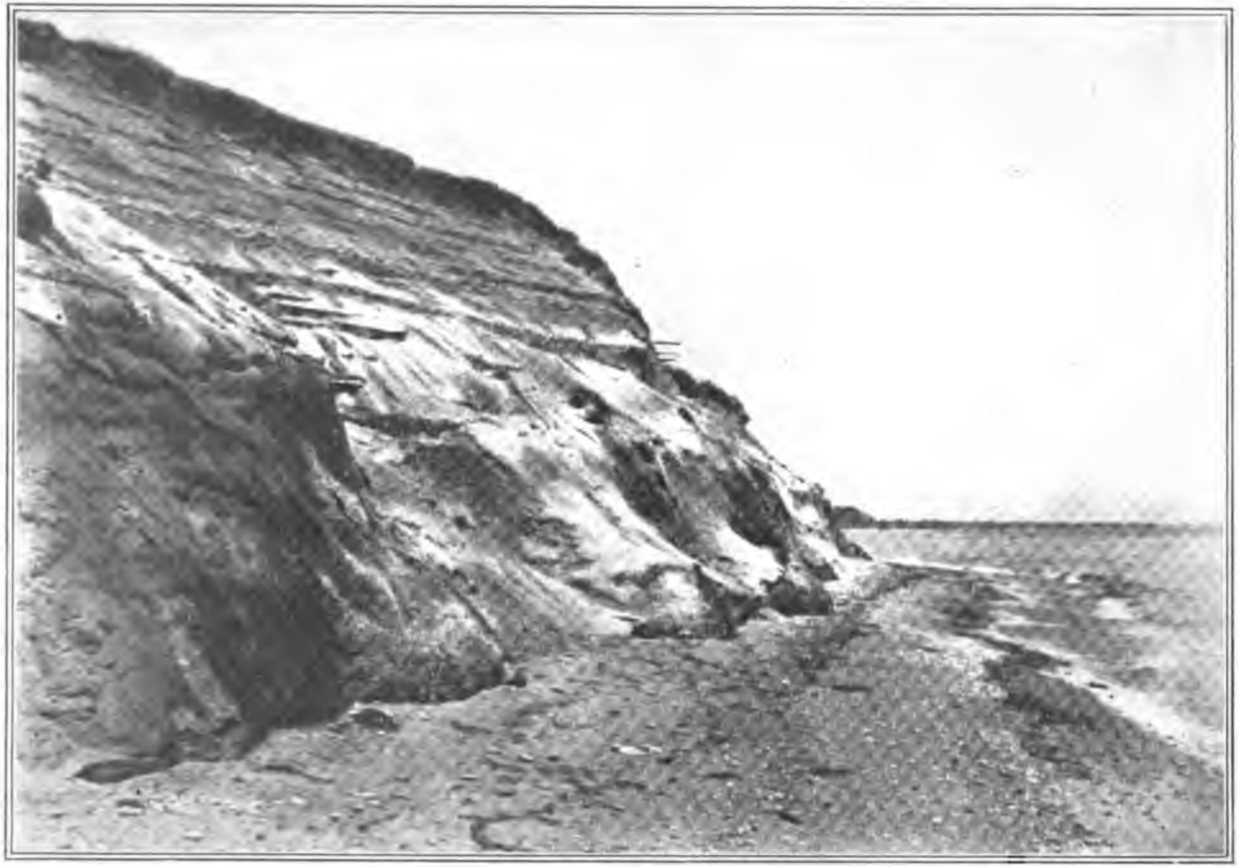
*See Sherzer's report on the Selkirk glaciers for the Smithsonian Institution, 1908.
†Compare also Leverett's list page 4 of the Ann Arbor Folio.



BEACH DEPOSITS, GRAVELS. ALGONQUIN BEACH GRAVELS, EXPOSED BY PRESENT CUTTING.

ter, a lake may have existed in which the red clays so abundant around Lake Superior were laid down, and the clay and till of this ice age may have been carved into drumlin form by later invasions. Then came invasion from the northwest from the Labrador center. Around Ann Arbor on the Huron just below Ypsilanti, and at other places cuts have been made down into hard, dark, older looking till which have been thought by Leverett's perhaps to represent the Illinoian stage. It does certainly seem as though it were quite a little older than the till lying on top, and we know that drift of the Illinoian stage came across Michigan to Illinois from the Labrador ice fields at that time. "It is also probable that this state was covered by ice at the Iowa stage, for the Iowan drift sheet is well displayed on the west side of Lower Michigan outside the limits of the Wisconsin drift." We

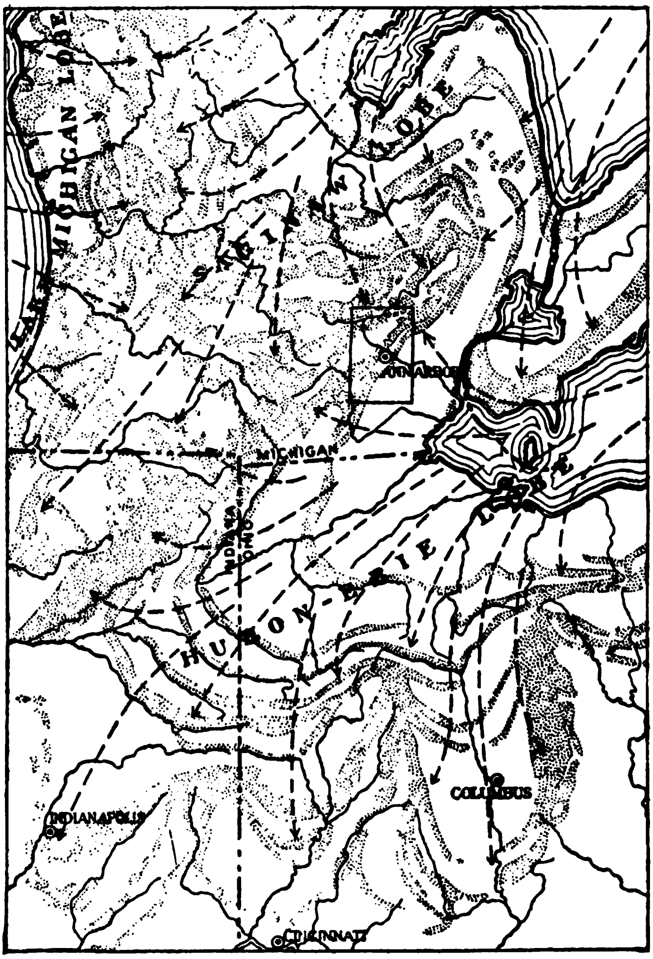


Figure 9—Sketch map of moraines of till left in its retreat from the Ohio River by the Erie-Huron ice lobe. This was formed by the currents of ice that followed the valleys of these lakes. After Fig. 5, Ann Arbor Folio, U. S. G. S. See also Monograph XLI.

may expect, therefore, to find remnants of these earlier till sheets here and there where, owing to some favored condition, they have not been eroded away by the later ice sheet. But to identify these sheets one would have to be very familiar with their characteristics and also have samples. Very few borings or drillings record the character of the drift beds encountered between the surface and the bed rock with sufficient care to even guess at any such separations. In fact the drillers rarely recognize till and very rarely keep samples of the "surface," so that while we can be pretty sure of the earlier till sheets it is quite impossible as yet to determine the same or to tell how and in what directions the ice may have retired or advanced.

The last, and to us the most important, movement of the ice was that of the Wisconsin ice sheet. This came to us mainly from the northeast, in a general direction from Labrador, and was, we may believe, not very thick, at least during its waning time, for at that time it seems to have been guided very largely by the greater valleys of the surface of bedrock beneath, shown in Plate VI. One great tongue spread down Lake Erie, meeting one from Lake Huron. Another great tongue reached down Lake Michigan. A shorter one considerably checked by the hard rocks which cross the neck of Saginaw Bay is called the Saginaw lobe. As its farthest extent the ice reached as far as the Ohio river, (Fig. 9), and then the general trend of the ice motion was from the northeast but as the ice waned the lobes more and more appeared and the course of the ice was shifted, the direction of the ice motion as indicated by the scratches on the rock, by eskers, etc., being always at about right angles to the margin of the ice. Thus as the ice waned and the ice front came less and less far south the ice scratches veered, instead of being from the northeast, and the general rule will be found to be that they veer from northeast so as to be more nearly up the general rock slope. The ice spread out by way of the great valleys now occupied by the Great Lakes and thence rolled as it were up on to the higher lands of the rock surface.

Thus the ice front was composed of a series of curves marked by moraines between which were sharp points or reentrants pointing north. Into these reentrants streams from the ice tended to wash great quantities of stratified drift. In retiring from its position on the Ohio the first place where the ice front reached Michigan was near South Bend and Niles (Fig. 10). Here an early line of drainage followed the Dowagiac and upper St. Joseph rivers and went past Buchanan and South Bend into the great Kankakee marsh and sand area.*

On the west side was the Illinois ice lobe coming down Lake Michigan. The moraines at the edge of the lobe Leverett calls the Valparaiso moraines. They run almost parallel to Lake Michigan up as far as Grand Rapids. On the other side were moraines from the Saginaw Valley in which fragments of coal occur quite abundantly.

THE GLACIAL LAKES.

When the ice had thus retired from its frontage on the Ohio, and Mississippi and Missouri valleys so far north that, as the land *then* stood, there was a slope toward the ice front, lakes were formed along the edge of the ice (Figs. 12 to 16). These drained over the lowest point or points to the south where discharge could be obtained. As the ice retired they flowed together by channels opened up next to the ice until at one time a great sheet of water covered most of the Great Lakes region.

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*Leverett, The Illinois Ice Lobe, U. S. G. S., Monograph XXXVIII, Plate XV, p. 342.

When two lakes thus flowed together one of the outlets might be deserted[1] entirely, or the lake might and often did have two outlets at once. Sketch maps showing successive stages in some of these lakes have been prepared by Taylor and Leverett and are here reproduced.[2]

THE RETREAT IN LAKE MICHIGAN.

It will be impossible to follow the retreat of the ice front, which is what really determined our surface geology, everywhere all at once. It will be convenient to take it in Lake Michigan first, both because it has been recently and carefully studied there by Goldthwait and because Lake Michigan so lies from north to south as to make the story except in its later stages much more simple and readily understood.[3]

LAKE CHICAGO.

When the ice retired from the Valparaiso moraine on the west side of Dowagiac a lake soon formed in front of it, which discharged through the recently reopened Chicago outlet and has been called Lake Chicago. A number of minor ridges of the retiring ice have been recognized by Leverett.[4]

Around and about these ridges Lake Chicago extended. But in a number of cases, back of St. Joseph, South Haven, New Richmond, etc., there may have been earlier and separate lakes, the exact histories of which will make pretty problems for local students.

(a) Glenwood 60-foot beach.

The highest level of Lake Chicago is shown by a stony beach just east of Holland on the south side of Black river at 60–65 feet (640 A. T.). This beach has been called the Glenwood beach. Higher water level signs around Vriesland and Overisel may be due to one of the smaller earlier lakes.

The extensive sand plains in Allegan county back of the Valparaiso moraine seem to be a delta deposit in this lake and run from 70 to 90 feet above the lake.

While this 60-foot stage lasted the ice retreated at least as far north as Sheboygan and Manistee, perhaps farther, but if so it returned and wiped out the beaches made.[5]

The lake may then have fallen in level materially during the retreat of the ice, possibly even lower than its present level. River channels are found to have been cut in the till to lower levels than the present bottoms. It very possibly connected at times with Lake Nicolet (Fig. 16) at the head of Green Bay.

(b) Calumet 40-foot beach.

With the readvance of the ice the channels which may have been opened to drain off the lake to a low level, probably somewhere on the eastern side of the Lower Peninsula were plugged up and the water once more escaped to the south, finding its way to the south to the Desplaines and Illinois rivers by a slightly different outlet—at Summit instead of three miles south.

It did not rise so high as before by about 20 feet, and this 40-foot beach is known as the Calumet beach. During this second stage the ice lay in the north end of the lake, extending from time to time as far as Manistee and Manitowoc, and wiping out the beaches that may have formed along the shore during its recessions and building heavy moraines now cut into by the lakes. (Fig. 12).

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[1] If one of the outlets was so much lower than the others that it could carry the discharge of all the lakes without being raised enough to have even its top higher than the bottom of some of the other outlets.

[2] Chamberlin, III, pp. 390–400. Also Ann Arbor folio, No. 155, U. S. G. S.

[3] Goldthwait, J. W. 'A reconstruction of water planes of the extinct glacial lakes in the Lake Michigan basin." Journal of Geology, Vol. XVI, (1908) p. 459.

[4] Monograph XXXVIII, U. S. G. S., p. 386, to wit: The outer ridge from east of Benton Harbor through Baroda to Three Lakes. The Covert ridge from Hutchinson Lake, northern Allegan, through E. Saugatuck, South Haven, Covert, St. Joseph, etc., only a mile or two from the lake. The Zeeland ridge or May Hill just north of the Pere Marquette track between Grand Rapids and Holland. These ridges are clay or clay loam—typical till.

[5] Goldthwait, Abandoned Shore Lines of Eastern Wisconsin, Wisconsin Geol. Sur. Bull. 17, p. 42.

When the ice withdrew finally from the region of Manistee and Muskegon there was a great drop from the Calumet beach, very likely even below the present water level and the drowned river valleys now occupied by the "daughter lakes," which fringe Lake Michigan so conspicuously may have been carved. But this was due to the blending of Lakes Michigan and Huron (and for that matter Superior too) in one great expanse of water which has been called Lake Algonquin, and the story of Lake Algonquin must be postponed until we have brought down the story of the other lakes of which it was composed.

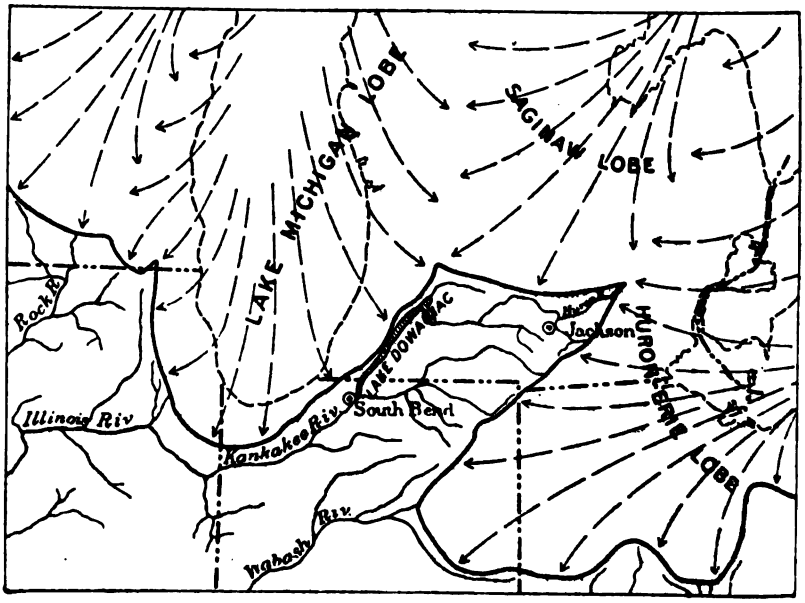

Figure 10—Course of drainage from Southern Michigan by way of the Kankakee, after Leverett. Fig. 6, Ann Arbor Folio, U. S. G. S.

One final comment. So far as we now know the beaches of Lake Chicago contain few or no shells. Lake Algonquin contains more. This may be because the earlier lakes were filled with ice water, clouded with glacial silt, and were thus unfavorable to life, whereas toward the end the ice had but little frontage on Lake Algonquin.

RETREAT OF THE ICE TO THE SAGINAW VALLEY.

We have said that the ice front first reached Michigan near South Bend and the sand burdened waters drained off to the great Kankakee marsh. The moraines from the reentrant angle circle Lake Michigan in one direction and curve about Saginaw Bay in the other (Fig. 10).

As the ice returned the reentrant worked north. Its position as marked by the gravel plains around and south from Kalamazoo when the reentrant angle was in the great ridges southeast of Gun Lake.

Another position (Fig. 11) was when the great kame of Dias Hill (T. 5 N., R. 11 W.) in the south part of Kent county was piled up, the drainage following Gem river to the south, and making the Green Lake outwash plain.

Another retreat brought the reentrant back to Plainfield north of Grand Rapids, and the gravels upon which Grand Rapids is built were washed out in front of the moraines, the hill around East Paris being formed by ice that came from the Saginaw Valley. The waters ran into Lake Chicago and built up the sand plains of western Allegan county—"Saugatuck" sands.

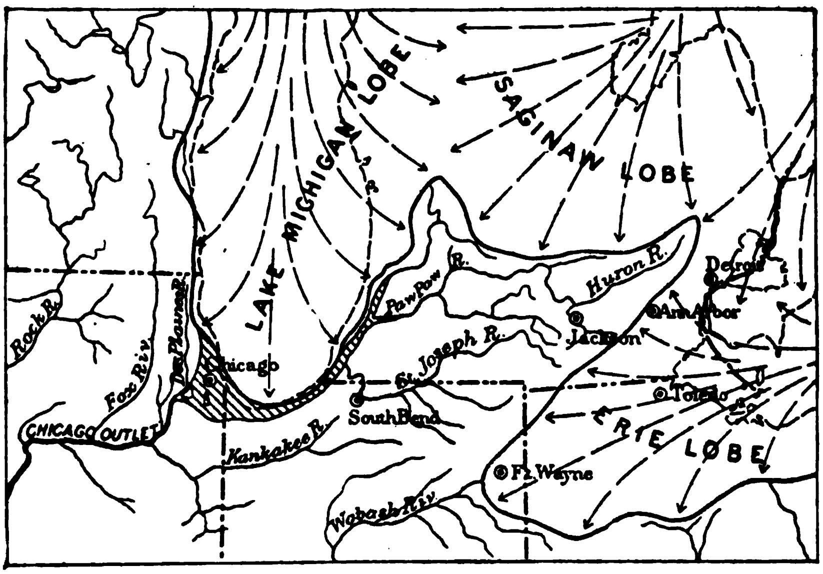

Figure 11—Course of drainage from Southern Michigan by way of Lake Chicago, after Leverett.

In melting back from this the next stand Leverett notes is near Cedar Springs, whence the ice front went to the southeast toward Alto, while to the southwest it passed near Englishville, helping to pile up a belt of high rolling land just west of Grand Rapids, and thence towards Hastings and Mason.*

In the meantime the rivers in the southwestern part of the state, the St. Joseph and Kalamazoo, had been developing. Fed and started at first by floods of waters from the melting ice, they often flow in heavy gravel plains. Their valleys are notably of two kinds. They may be valleys between moranic belts of till, which are very often covered with outwash gravels. Or they may be valleys, where mighty streams coming from the ice have cut through the moraines, either preventing their formation or washing them away. They are very often followed by railroads. The Michigan Central from Lawton to Niles, the Grand Trunk from Battle Creek to Charlotte are good illustrations.

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*See annual report for 1901, pp. 84, 85.

As the ice tended to occupy the lowlands a peculiarly unnatural form of drainage was produced, and there has doubtless been rearrangement in very many places. The upper parts of the Kalamazoo, and the St. Joseph, and the part of the Grand River that lies about Jackson or even Eaton Rapids are much older than the lower parts. Indeed it seems that parts of the head waters of the Huron river in Oakland county, and even of country now draining into Lake St. Clair once drained first past Jackson, then past Eaton Rapids to the southwest.

Two things to be noted are the relatively rapid disappearance of the ice in its waning stage of glaciation from the higher parts of the rock surface, and the relatively little vigor with which the ice pushed over the Saginaw Valley. This may be attributed to the fact that right across the neck of the bay from Huron county to Arenac county through the Charity islands is a rock ridge.

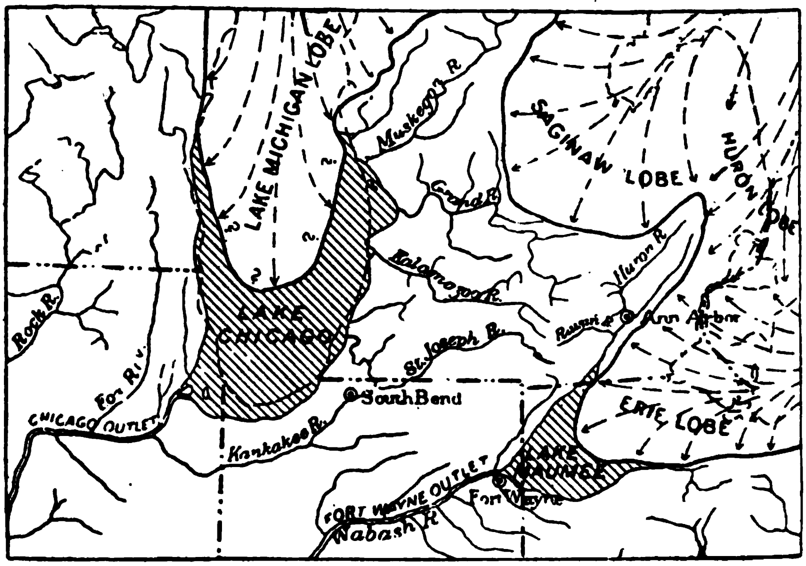

Figure 12—Course of drainage from Southern Michigan by way of Lake Maumee and Lake Chicago. After Leverett.

Though Michigan is full of lakes they must have been much larger, and many large lakes which once existed have ceased to be. This process is indeed now going on. There is opportunity for indefinite and very attractive outdoor local work in tracing out the history of individual lakes and regions and placing them so far as possible in the general succession of events, as here outlined.

EARLY LAKES ON THE EAST SIDE OF THE LOWER PENINSULA.

Lake Maumee.

(a) Van Wert Stage (793 A. T.).

As soon as the ice in its retreat passed the divide between the Maumee and the Wabash in Indiana, near Huntington, not far from Ft. Wayne, a lake shaped like an arrow head began forming in front of the ice and the marginal moraines formed by it. The Huron and Raisin soon found their way into this (Fig. 12).

A well marked moraine has its apex near Defiance, Ohio, and thence passes northeastward through Adrian, Michigan, between Ypsilanti and Ann Arbor, and so north to a reentrant angle between the Lake Erie and Lake Huron ice tongue and the Saginaw Valley ice somewhere in Lapeer county.* (Plate IX.)

When the ice ceased to reach the Defiance moraine the waters of the Lake worked around in behind it (Fig. 13) leaving it in islands, and of course the water was at first at the same level. But as this beach is traced north it is found at present higher and higher up. This is a phenomenon we find over and over again repeated and must be due to an uplift, increasing to the north, combined to some extent with the readjustment of lines of equal level, as previously explained. From 793 feet at Adrian it rises to 800 or 812 feet A. T. at Ypsilanti, and Ann Arbor, and reaches 850 and perhaps more further north. The addition of a second outlet lowered the level of the lake and of the water in the first until the outflow reached a balance.

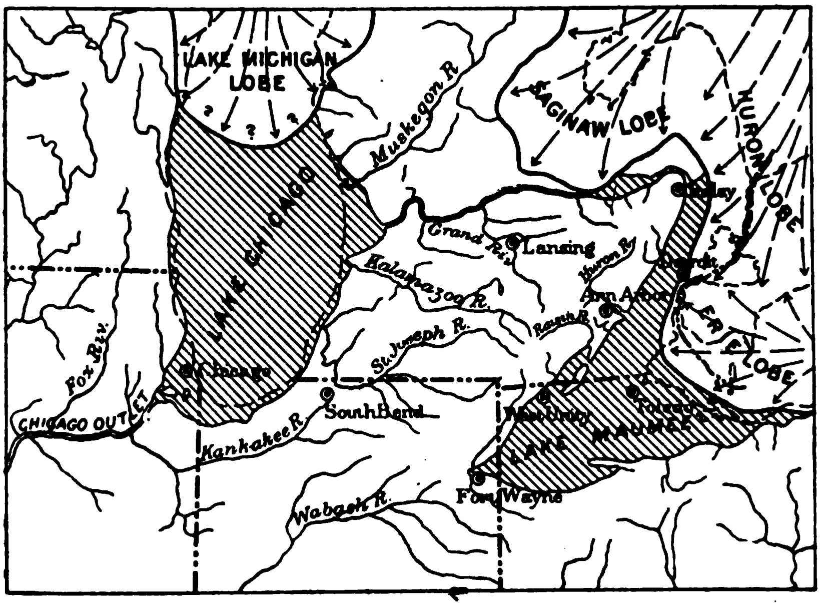

Figure 13—Course of drainage by Imlay outlet and Grand River valley (Pewamo outlet) after Leverett.

(b) Leipsic stage (Second Maumee Beach).

Finally the ice front retreated far enough so that a channel was opened in Lapeer county (see Plate IX,) by way of Imlay City and the Flint river drainage down to a lake which had formed in the Saginaw valley and was discharging by way of the Grand into Lake Chicago. In order to balance this extra outflow the discharge by way of Ft. Wayne was cut off by drop of the lake level so that the Ft. Wayne outlet from being 15 to 20 feet deep was only 5 or less, a mere regulator or waste weir, the main channel being that of Imlay City. These channels are clearly brought out on the map of surface geology, being bottomed with sand and gravel or swampy, and not till. Plate XII.

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*Annual report for 1901, Plate VI.

The beach is 15 or 20 feet below the upper one, being about 825 feet A. T. at the Imlay outlet.

With the next retirement of the ice the lake spread so as not merely to cover the flat area southwest of Erie and Huron, but absorbed the Saginaw Valley as well, and thus has received a special name.

A third beach 20 feet lower yet may mark the culmination of a recession between the times of the first and second, and seems to have been washed over by readvances.

Lake Arkona—Arkona Beaches. Defiance Moraines

When the ice left the moraines in the northern part of Wayne county it seems to have retired quite rapidly and to a distance that left open complete water communication around the Thumb.* Of course this was by degrees, and water channels opened across the Thumb. Of these there are many, some of which may have begun work at this time, others certainly later. Lake Arkona, like Lake Warren (Fig. 15), then covered a good part of Lakes Erie and Huron and stretched from the highlands of Arenac county to the highlands back of Buffalo. There thus seem to be two, rarely four, beaches belonging to Lake Arkona, and whether these are due to the gradual opening of channels across the Thumb, to cutting down of Grand river outlet, or whether even there were outlets opened in New York state† is not fully determined.

The next step in ice history was very interesting. The ice front readvanced. Lake Superior was cut off by itself once more; the Pt. Huron moraine wiped out part of the beaches, while near the point where they were wiped out and facing the moraine great strong beaches remain.‡

RETREAT OF THE ICE FROM THE NORTHERN HIGHLANDS.

During the time of Lake Arkona and the retreat of the ice front the reentrant between Lake Michigan and Saginaw Bay must have gone back so as to leave all the great highland north of Saginaw Bay uncovered. The readvance at the close of this time in Lake Huron reminds one of the readvance of the ice in Lake Michigan to the Manistee moraine. One is tempted to speculate if the retreat went so far as to open some passage to the north where the land was then depressed and drop the water level even below the present. Signs of some such interruption by a great drop of water level during the existence of Lake Chicago have been noted. In that case the recognized Arkona beaches would mark certain late stages in the readvance of, and the higher levels of Lake Arkona. The lower ones would be wiped out or inextricably worked over and into the series of later beaches.

We had followed the retreat of the angle between the Michigan lobe and the Saginaw lobe back a little way north of Grand Rapids. So far it had been a rather sharp and definite point. But in retiring farther past the high land in the Lower Peninsula (1722 A. T.) near the junction of Osceola, Wexford and Missaukee counties, it probably ceases to be so defi-

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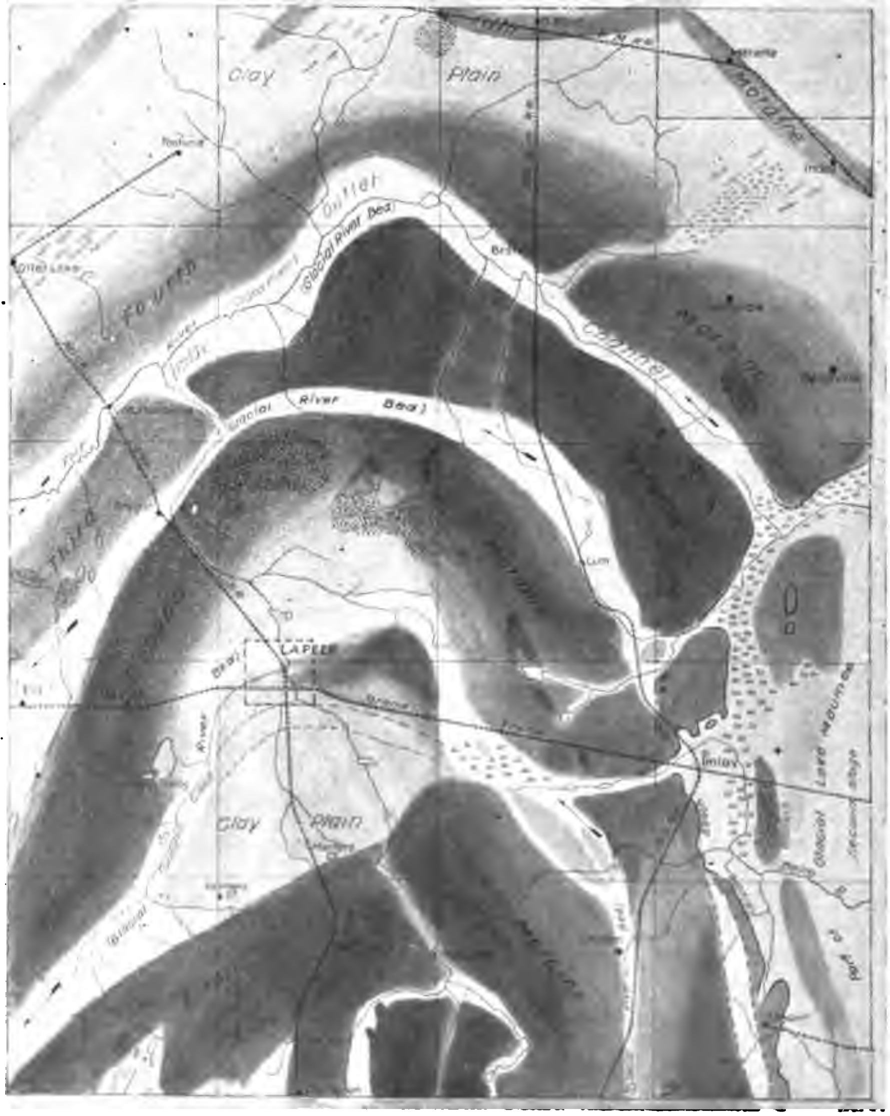
*Taylor. Seventh Report Michigan Academy of Science, pp. 32–33.

†Fairchild, H. L., Glacial Waters in Lake Erie Basin, N. Y., State Education Department, Bulletin 393, Feb., 1907, being Bulletin 106 of the N. Y. state museum.

Fairchild, p. 42 and 64, 75, believes that the ice front did not retire so as to let Lake Arkona reach N. Y. state at all, but if there was a drop between the two stages of Lake Chicago to a level below that of the present lakes, there may have been an even greater retreat and lower beaches of the Arkona interval.

‡Taylor. Seventh report Mich. Academy of Science, p. 32.



SURFACE GEOLOGY OF LAPEER COUNTY.

nite. The ice tongue coming down the Lake Michigan valley moved out against an irregular "knobstone" topography and a double escarpment made by the harder beds of the Lower Carboniferous and Marshall sandstones and the Upper Grand Rapids or Bayport limestones, and the eastern margin of the ice tongue against the high land was broken into spurs.

Floods of sand and gravel were washed out from the ice and when readvance came scraped up from these extensions of the lake shores formed during the times of especial retreat. Thus the *very moraines themselves became sandy and gravelly*, and a broad area was formed between the side moraine of the Lake Michigan tongue and that of the Saginaw ice, in which the drift was piled hundreds, yes in places probably over a thousand feet thick. The rise from 700 or 800 foot contours to 1100 or 1200 A. T. is very sudden, and Cooper* has called attention to the relatively large percentage of territory between 1100 and 1300 A. T., nearly twice as much as there is between 900 and 1100 A. T.

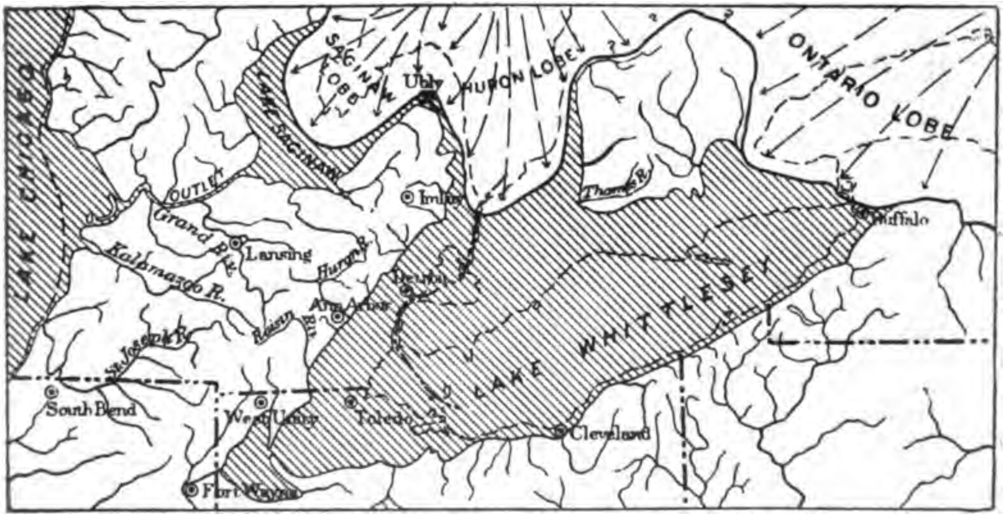


Figure 14—Lake Whittlesey and the Ubly outlet, after Leverett.

The course of the moraines and the position of gravel and sand plains is shown in Leverett & Nellist's (Plate XII) maps.† But it must be remembered that the moraines of this area are of relatively light and sandy material. Numerous undrained lakes and hollows probably mark where fragments of stagnant ice were left buried in the gravel in the relatively rapid retreat of the ice front. The area was drained by the Muskegon, into which flowed parts of the AuSable and Manistee.

LAKE WHITTLESEY. BELMORE BEACHES.

With the cutting of Lake Arkona in two parts by the readvance of the ice front, the name Lake Saginaw is once more applied to that part of the Saginaw valley, but that east of the Thumb has been called Lake Whittlesey.

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*Ninth report Academy of Science, p. 140.

†Fuller details of the stages of retreat will be given by F. Leverett in a forthcoming monograph.

This latter drained into Lake Saginaw by channels (Fig. 14) across the Thumb leading down into the Cass river valley, channels out of all proportion to the present size of the streams in which they can scarcely maintain themselves. The one past Ubly is the strongest, and the water line was there 809 A. T.

Lake Whittlesey extended from the Thumb to Marilla, N. Y., a village south of Buffalo. That this readvance was one of some duration is indicated by the persistence of the so-called Belmore beach, made at the time.

Around to Birmingham the level of the Belmore beach is quite flat, the crest being 739 A. T. At Lake Ridge in the northeast corner of Lenawee county the elevation is 736 A. T. Thence the beach is found at higher and higher elevations, owing either to the ice attraction or to the depression of the crust of the earth under the extra load of ice and water. Both explanations must be true to some extent. Fairchild finds in New York a similar rise at a rate up to 2.1 feet per mile in 26 miles, but in 74 miles 1.64 feet per mile.*

In Michigan a rise of (809–739) 70 feet is mainly concentrated in 60 miles. At one stage in the existence of Lake Whittlesey, before it broke fairly open to the Lake Saginaw valley, it may have reached clear around the point of the Thumb, the last holding ground of the ice determining higher levels being the moraine north of Mud Lake, Grant township, Huron county. Around Bad Axe at 774 A. T. the shore lines belonging to this naturally merge with the shore lines belonging to the next stage.

LAKE SAGINAW.

The exact relations between Lake Whittlesey and the Arkona beaches and those corresponding to the Belmore beach in the Saginaw valley have not been worked out. As the outlet of the lake in the Saginaw valley was all the time the same, through the Grand Maple river channel or Pewamo outlet as it has been called, which rests at Ionia and elsewhere on a rock sill, there is no reason why in the Saginaw valley there should have been any material change in height of shore through all the time of Lake Arkona, Whittlesey and the beginning of the succeeding Lake Warren. If the up grade near the ice was as usual it would tend to raise the water level somewhat when it advanced, and there may have been a clearing out of the till on the floor of the Grand River channel. A heavy set of beaches shown on the map start at 760 feet A. T. or so, where they merge in the heavy gravel deltas of the Ubly outlet of Lake Whittlesey around Cass City, and decline toward the Pewamo outlet, grazing the S. E. corner of Saginaw county at 728 A. T. and below. The highest part of the Pewamo or Grand-Maple river outlet is not over 80 feet above Lake Huron, 660 A. T., but this outlet must have been quite deep at first, as it may have carried a stream comparable to Niagara. It is also quite likely that its bottom was at first glacial drift, and slowly cut down, somewhat as the St. Clair river is now doing at Port Huron, until it reached a bed rock sill near Pewamo and Ionia, which would then be the fulcrum from which the tilting of the beaches would be reckoned.

LAKE WARREN. FOREST AND GRASSMERE, BEACHES.

When the ice retired finally from the Port Huron moraine after the Belmore beach was formed, the water level in the Lake Erie-St. Clair valley dropped back to that of Lake Saginaw, and the outlet by the Grand river valley was for a while the only one for a vast lake extending from the highlands north of Saginaw Bay to New York state (Fig. 15).

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*Loc. cit. Glacial Waters in Lake Erie Basin, pp. 77, 78.

This retreat, like the retreat during the time of Lake Arkona, may very likely have gone back so far that other outlets than the one by Grand river, either around the north end of the Lower Peninsula or across the state of New York, past Syracuse and down the Mohawk valley to the Hudson, were opened. But if so they were closed by the readvance of the ice, and the waters rose to the highest shore line of this lake.

The higher shore lines are called the Forest shore lines* and skirt the Thumb of Michigan, from a little north of Bad Axe and at an elevation of about 774 A. T. to 744 A. T. declining where they leave the county, to 729 A. T. to 757 A. T. These are unquestionably connected with the Grand river outlet and that alone.

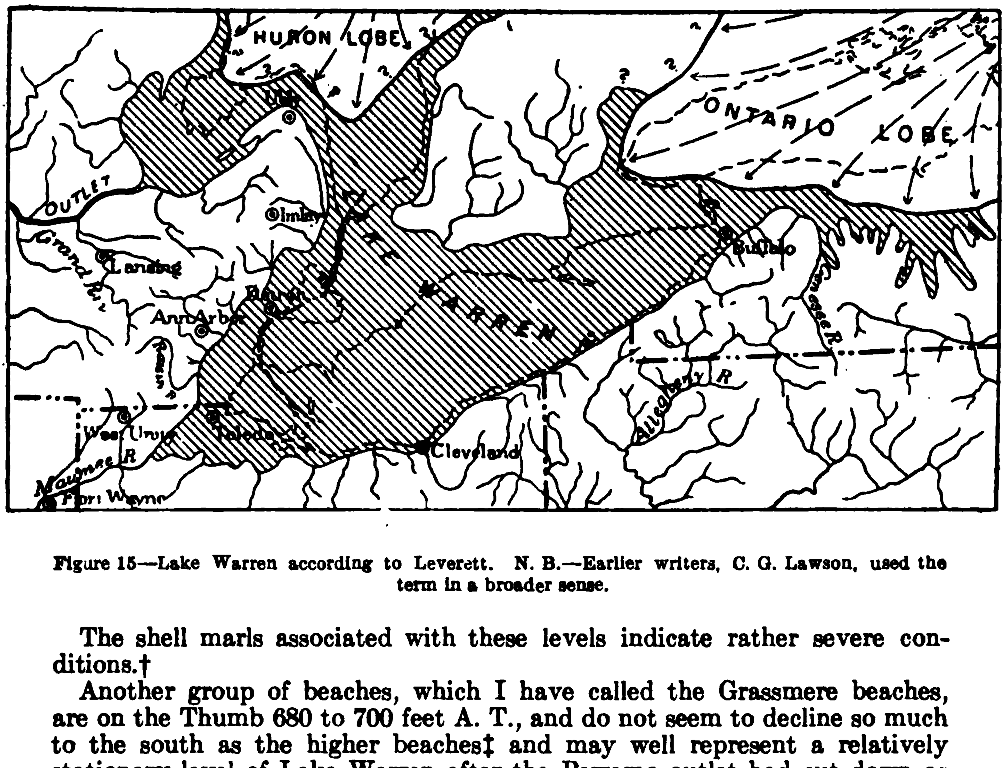

Figure 15—Lake Warren according to Leverett. N. B.—Earlier writers, C. G. Lawson, used the term in a broader sense.

The shell marls associated with these levels indicate rather severe conditions.†

Another group of beaches, which I have called the Grassmere beaches, are on the Thumb 680 to 700 feet A. T., and do not seem to decline so much to the south as the higher beaches‡ and may well represent a relatively stationary level of Lake Warren after the Pewamo outlet had cut down as far as it conveniently could (or was acting as a spill way to some other outlet), and after the ice had retired so far that its effect in making the beach rise to the north was less noticeable.

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*See U. S. G. S. Water Supply Paper, 182, Pl. V

†Huron county report, Mich. Geol. Surv., Vol. VIII, Part 2, Chapter X, Sec. 2.

‡Compare the Woodland Avenue beaches in Cleveland, and Fairchild's table on p. 65 of the "Glacial Waters of the Lake Erie Basin." If we take, as Fairchild's table suggests, 70 feet below the Whittlesey or Arkona beaches in Lake Saginaw we shall get the Grassmere, which *may* be what has been called the Lower Forest.

LAKE DANA. ELKTON, ETC., BEACHES.

The next drop was a marked one to a level in Huron county 647 A. T., the Elkton beach. There was a marked sharp halt at this level and then a drop to a level sharply but faintly marked at 635 A. T., at the Thumb.

For the Elkton beach the Pewamo channel can hardly have been an outlet. This must unquestionably have been to the east along a line south of the N. Y. Central down the valley of the Mohawk to the Hudson. A magnificent series of channels running in this direction along the edge of the ice front have been mapped by Fairchild and the lake called Dana.[*]

The ice front which had been holding the lake up to a level of the Pewamo outlet retired, and somewhere near Marcellus, N. Y., retired so far that water (standing at 880 A. T.) began to find its way around the ice front from Lake Warren into the Mohawk valley. For a short time there would have been two outlets, the amount carried through the Pewamo channel decreasing and the water level there lowering until the amount of the new channel by the ice was balanced. This is just the sort of thing indicated by the Grassmere beaches.

The shore lines at 647 A. T. and 635 A. T. are sharp as to elevation, but relatively weak. It is impossible to connect them with any particular channels as yet.

In Bay county where at this time there seems to have been relatively rapid building of sand ridges the record is more complete, and as given by Cooper[†] we find the following beaches with their respective elevations;

Grassmere, 688 A. T.
Section 5, Garfield, 667–674 A. T.
Section 16, Garfield, 660 bottom to 669 top.
Elkton, 642–650 Williams township.
Saganing, 625 bottom, 633 top, very persistent.
Section 19, Kawkawlin, 610 bottom, 620 top.

LAKE ALGONQUIN. TOLESTON BEACH, ETC.

While the ice was retreating from New York and the Mohawk valley it was also retiring from Lower Michigan. The resultant lake extended into Lake Superior, Lake Michigan, Lake Huron, and would also have covered Lake Erie, but as soon as the ice front retired far enough the water in the Ontario basin dropped to the level of a lake known as Lake Iroquois, Niagara began to work, Lake Erie drained that way and was even lower than at present perhaps at its west end. The upper lakes would have drained about as at present, but that soon after the Mohawk valley opened there was probably an outlet to the Ontario valley (Lake Iroquois) by way of the southeast corner of Georgian Bay, the "Trent outlet" which was so depressed, though now it stands 875 A. T., that the water for a while flowed that way and may have been lower than at present in the south ends of Lakes Huron and Michigan. However, the land around this outlet was rising as the ice retired, and the water soon found its way once more to the south, past Chicago (the Toleston Beach) and past Port Huron. The St. Clair river is cutting down its channel. The Algonquin beaches are being studied by J. W. Goldthwait. His result[‡] up to date is that about

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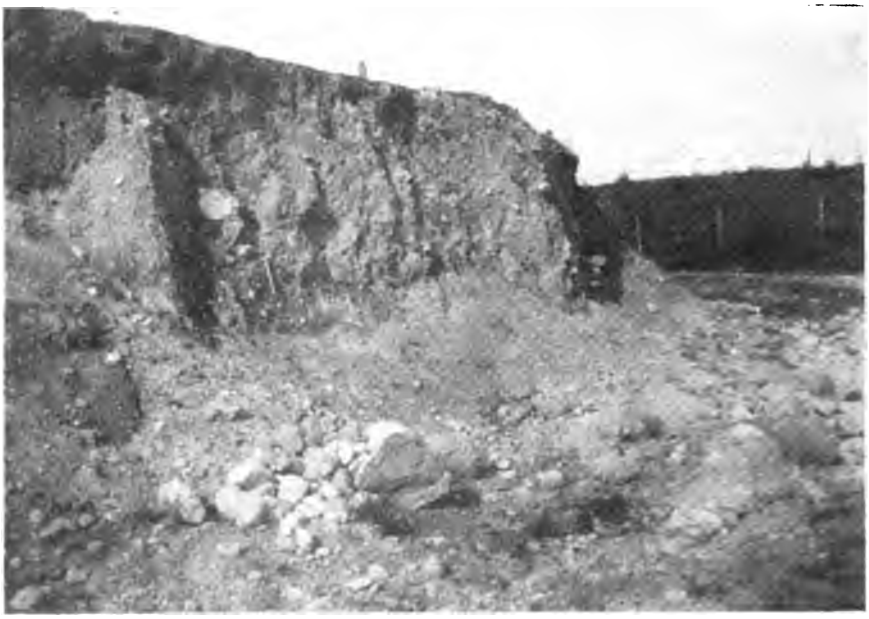
[*] Bull. G. S. A., X, 1899, pp. 27–68.

[†] Bay county report. Annual report for 1905, pp. 344–348.

[‡] Abandoned shore lines of Eastern Wisconsin. Bull. XVII, Wis. Geol. Survey. Am. Assoc. Adv. Sci., meeting Dec.–Jan., 1907–08.



TILL OR BOULDER CLAY.

the south end of the lakes the highest Algonquin shore line is nearly horizontal, and the crest of the beach 25 feet above the lake, and is the Toleston Beach of Lake Michigan. In the Saginaw valley faint swells of the surface laid down by the ice under the waters of Lake Saginaw, with beach spits upon them, cut off from the main expanse. lakes like those at the ends of Lakes Erie and Superior at present, and there are numerous other lakes,[*] which began their existence in the same way.

Benches in front of the cut Algonquin shore line are often only 17 to 18 feet above the lake so that the highest *water* level is, say about 600 A. T.

This vast lake had an extremely well marked beach line, which in contrast to those preceding contains shells[†] (Unio, etc.), in such abundance as to show that the ice had relatively little effect upon the waters. In fact the ice front may have touched it, for at least a good part of its considerable duration, only in one relatively narrow tongue north and east of Lake Nipissing where the Nipissing outlet later to be used was still filled with ice. The Trent outlet was probably soon uplifted and ceased to work. The means of discharge were then reduced to the Chicago outlet, which probably carried but a small part of the water, and the Port Huron outlet, much as at present. During the life of Lake Algonquin the St. Clair delta may have begun to form.[‡]

As the uplift to the north continued a series of water levels and beaches were produced which converge toward the Port Huron outlet. If the Trent and Port Huron outlets were at first so low that the Chicago outlet did not work at all, the low beaches down at the south end of Lake Michigan could be covered over so that the Toleston beach may not represent really the oldest beach there.

Each distinct uplift would make a new water line and at Mackinac Island and St. Ignace there are some ten of them from 812 to 760 feet A. T. Then at 716 feet A. T. is a well marked Battlefield beach. Then from the 680-foot beach down are a lot belonging to the Fort Brady group. The lower beaches are not tilted so much, and all converge so that by the time we get down to Manistee they are together. South of this signs of tilting do not appear. Some years ago I called attention to one sign of this recent northward elevation of practical importance in the fact that the streams north of a line through Port Huron and Frankfort have a steep grade and water powers near their mouth. An elevation of the outlet at Port Huron seems also to be indicated by the "drowned" or dead water state of the streams south of this line and of some streams like the Saginaw which flow toward the direction of uplift.[§]

These uplifts presumably took place during the retreat of the ice front after the time the Trent outlet was opened, and the waters on both sides of the Lower Peninsula flowed together. One reason perhaps why there is so little sign of tilting in the south part of Lake Michigan is that that part of the earth's crust had been uncovered much longer during the time of Lake Arkona and Whittlesey and had had time to get well settled once more.

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[*] Rice lake, Huron county, lakes near Pt. Tawas.

[†] See Huron, Bay county, and other reports.

[‡] This may have taken from 1,000 to 10,000 years. It is (see Part 1 of Volume IX) 14 feet deep and about 128 square miles in area, or contains about 49,000,000,000 cu. ft. A single summer storm Cole measured to bring down .033 to .04 ounces per cu. ft., and as the discharge is about 234,000 cu. ft. per second that will mean 430,000 to 510,000 cu. ft. a day. Wheeler estimated that 4,000,000 cu. ft. came down in a three-day storm. It would then take only between 100,000 and 10,000 such storms to build up the delta. As the storm Cole mentioned was not an exceptional summer storm, the precipitation being .60 at Port Huron, .78 at Detroit and .78 respectively, it might be safe to assume one a month for 10 months, 71 out of 104 summer months (March to October) having storms with greater 24-hour precipitation. Wheeler's storm may have been more exceptional.

[§] See Jefferson, M. S. W.; Bulletin, G. S. Am., 18, pp. 347–349.

Before the ice retired so far as to leave an outlet for the Lakes above Port Huron directly by way of Lake Nipissing and the Ottawa, which was the next great event, the uplift of the northern region was so great that no very great drop was made.

LAKE NIPISSING.

Finally the ice disappeared altogether from the basin of the Great Lakes. At first surely this must have caused some drop (30 feet or more) in water level, and probably the Port Huron outlet may have been deserted for a short time. But the progressive elevation of the north country would, and soon did, bring it up again so that the Port Huron outlet was once more used. But it did not rise to the same elevation because since part of the water went another way, not so large a channel was needed and by the time the elevation went so far that the Nipissing outlet was abandoned the Port Huron outlet had been cut deeper. So that the highest shore line of this lake is something like 10 ft. below the Algonquin and only 14 feet above the present lake on the Thumb and near Port Huron—the water level then not over 10 or 11 feet above the present lake level.

This vast sheet of water covering the great Lakes after the opening of the Nipissing outlet is known as Lake Nipissing. At first it had an outlet only to the north, but later, and probably soon, the Port Huron outlet was opened and probably for a very considerable time both worked conjointly. With the continuing uplift the volume of discharge was slowly shifted from the Nipissing outlet to the Huron outlet. With the final abandonment of the northern outlet the era of development of the present lakes may be said to have begun which has just closed with the reopening of the Chicago outlet and other modifications due to man.

The duration of Lake Nipissing is said by those who have studied it to be the longest of all the stages of lake development, judging by the amount of work done, the cutting of cliffs—the building of bars and sand plains.

This may be true in the northern part of the region but in the southern part where the Algonquin levels are bunched, say around Saginaw Bay, I should give the preference to the Algonquin. Taken together certainly the work done in Algonquin and Nipissing time and since seems far greater than that done at any higher levels. Around Northport the elevation of the Nipissing crest is 606 ft. A. T., at Charlevoix 612 ft., at Harbor Springs the base of the cut 613 ft., at Mackinaw City 627 ft. A. T., at Sugar Island 672 ft., A. T., according to Goldthwait.

RECENT LAKE SYSTEM. RECENT SHORE LINES.

Between the Nipissing shore lines and the present there are numerous shore lines due to the gradual cutting down of the Port Huron outlet and the continuance of the northward uptilting which according to careful observations is still going on.

Of course in the southern part of the basin where the interval between the Nipissing beach crest and those of 1886, 1838, etc., is less than 10 feet no farther divisions can be very well made out. Farther north where the beaches are separated by the uptilting there are shore lines at 8 or 10 different levels and one horizon, the "Algoma" 20 feet above the lake at Mackinac, has received an especial name.

With the artificial reopening of the Chicago outlet a new era may be said to have begun.

It is doubtful if the lakes will ever again reach the levels they touched in the past century. High water of 1838, formerly taken as 584.34 is now taken by White as 583.26, by the U. S. Engineers as 584.69. In June, 1886, there was another high water, 583.13 A. T., that is 1.21 below the 1838 high water, and this 1886 beach ridge was very well marked in 1895, when I was doing my Huron county work, being 4 or 5 feet above lake level then. The lake has since risen somewhat, but the 1886 ridge is still identifiable.

CHANGES NOW TAKING PLACE.

The shore line of these recent lakes is a well marked one, especially south. Cliffs at present lake level have, where cutting is going on, often cut away the traces of previous beaches, and apparently cut as deep a notch as any previous.

These changes are going on with a good degree of rapidity. Along the east shore of Huron county[*] rates of cutting from 2 to 6 feet a year were observed, averaging perhaps 3 feet a year, and at Point Aux Barques[†] (Plate XI), the recession of a bluff seemed to be something like 2 feet a year, 115 feet between 1835 and 1897. In Sanilac county a careful survey of a half mile of somewhat rapid erosion[‡] gave a loss of 27.25 acres in 79 years, 4.18 feet per annum, 1823–1859, and 7.2 feet per annum, 1859–1902, or 5.7 feet per annum. In extreme cases the cutting has gone on at the rate of a rod a year. Quite similar figures have been found as the losses along the Lake Michigan shore.

The clay bluffs along the Lake Superior shore from the Michigan boundary to Clinton Point are very rapidly retiring, if one may believe reports many feet in the past few years.

Now as to gains. Local accretion at the foot of Huron Avenue, Lexington, Sanilac county, was found to be 244 feet in 20 years. In other places it was from 10 to 30 feet a year.

The Harbor Beach breakwater has caused in spots 100 feet accretion in 20 years, and the engineer's blue prints show the stages.

Tawas Point is adding something like 60,000 square feet a year.[§]

Around Mackinaw City, though modified no doubt by improvements, as reported the terrace west of the dock has advanced 143 feet in 24 years prior to 1907, 250 feet in 35 years, 6 or 7 feet a year. The growth of St. Clair delta has been already described.

From such figures as these compared with the total amount of work at present levels one comes to estimates of this *recent* time of a few hundred years, and of all Nipissing time as possibly 3,000 years or so.

Records of the rate of such recent changes are of scientific value and are very gladly welcomed by the State Geologist.

The upward tilting of the north has been spoken of, and its signs in drowned river mouths in the south part of the basin and rapids and water powers in the north part of the basin. Moseley has studied these signs around the Toledo end of Lake Erie[||] at Cedar Point, and concludes that the rise of the lake Erie level due to the uptilting of the other (the outlet) end is about 2.14 feet per century, or at a rate of about 1 foot per century per hundred miles if the direction of rise is north northeast.

Between Milwaukee and Port Austin Gilbert found an apparent rise, correcting his figures, of 0.068 feet from 1876 to 1896.* Comparing gage readings at Milwaukee with those at Saginaw† may also give some results. Around Saginaw Bay in Bay county the shore line in many cases is close to the original meander posts, and this shore is so flat that any material change in level would be readily recognized. This is close to a line at right angles to the supposed direction of uplift, through the outlet, and shows no change in water level.

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[*] Volume VIII, Part 2, p. 80.

[†] Annual report for 1902, p. 14.

[‡] Annual report for 1901, p. 286.

[§] Annual report for 1903, p. 303.

[||] Seventh Annual report Michigan Academy of Science, p. 39.

The following table prepared by W. H. Sherzer may serve as a review and guide to the position of the beaches on the easily accessible strip from Ann Arbor to Detroit.

PREDECESSORS OF GREAT LAKES.

Name of Lake.	Beach.	Outlet.	Location of Beach on Electric Ry.	Elevation.
Maumee, 1st stage	Van Wert	Ft. Wayne & Wabash R.	1 mi W. of Ypsilanti	812 ft.
Maumee, 2nd stage	Leipsic	Ft. Wayne & Imlay City	Water Tower	794
Saginaw	Arkona	Grand River	Dentons	708–694
Whittlesey	Belmore	Cass River Valley	Wiards	736
Warren, 4 stages	Upper Forest		Canton	680
	Lower Forest[3]	Grand River	Wayne	655
	Grassmere	Around Lower Peninsula[3]	Inkster	635
	Elkton	Mohawk[3]	Dearborn	610
Algonquin	Algonquin	Trent Chicago Outlet Port Huron	Detroit	590
(Lowering of Mohawk bed brought Lake Iroquois into existence, over the present site of Ontario, and gave birth to Niagara River and Falls.)				
Lakes Nipissing	Nipissing	Ottawa & Mattawa R. Port Huron.	Detroit	580
(Detroit river out of commission and only waters of Lake Erie going over Niagara Falls, cutting the narrow part of the gorge.				

The elevation of land in Ontario shifted the outlet from the Ottawa to the Detroit river and raised the level of the water in it and Lake Erie.

The withdrawal of the ice from the St. Lawrence valley opened up the present outlet and gave rise to the present system of lakes.

THE ICE AGE IN THE UPPER PENINSULA.

The main principles and course of events during the ice age in the Upper Peninsula are the same as in the lower.‡ In both the ice followed the great main valleys, spread out and covered the highlands, and spread south. Then in retiring it left lines of unassorted material known as till at its margins, great sheets of gravel washed off in front of it, where the slope was away from the ice, and lakes and lake deposits where the slope was toward the

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*Huron county report, Volume VII, Part 2, p. 36.

†Michigan Miner, June, 1900. Annual report for 1905, p. 368.

‡The literature and history of the ice age in the Upper Peninsula can not be separated from that of other states, especially Wisconsin, and is not covered in the list by Leverett already referred to, Mich. Acad. Sci., 1904, p. 109), the work of Chamberlin & Salisbury and other pupils in Wisconsin, a popular account of which is given by Case, Wisconsin Geology and Physical Geography, 1907, and a resume in their recent geology, the original being in their geology of Wisconsin, should be consulted.

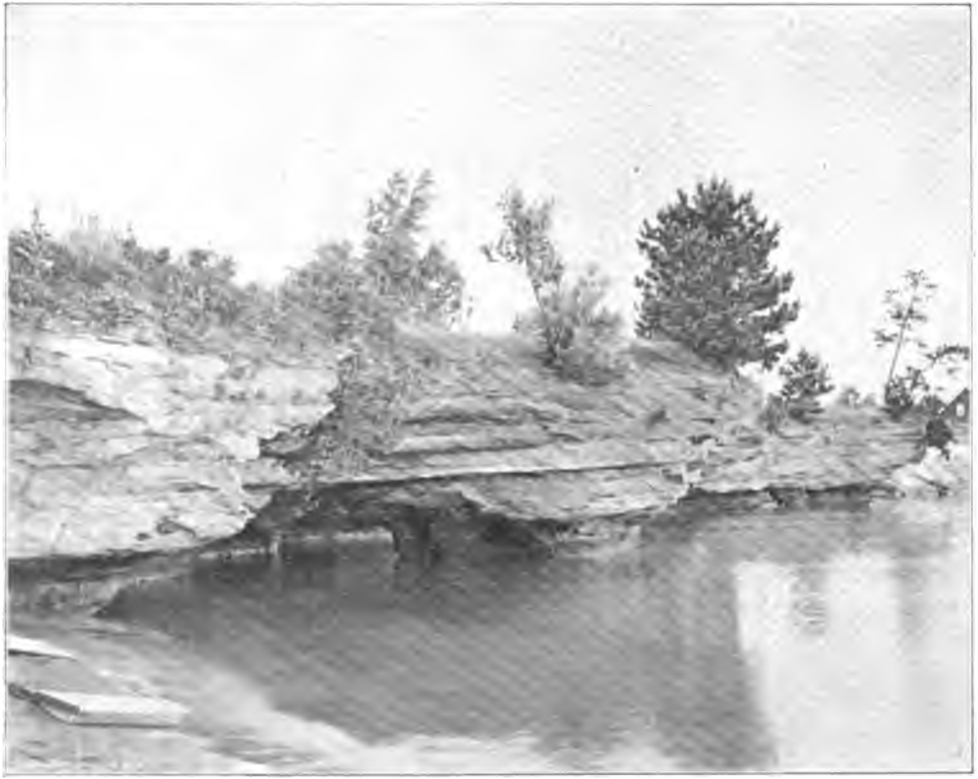
There are the two reports by I. C. Russell in the annual reports of the Board of Geological Survey of Michigan for 1904 and 1906, various papers by Taylor, mainly in the American Geologist, especially Vol. XII, 1894, p. 365, numerous papers by Upham (see especially Vol. VI, Bull. Geol. Soc. Am.), and an important paper by Lawson in the 20th Annual report Minn. Geol. & N. H. Survey. The bibliography given by J. W. Goldthwait, Bull. 17, Wisconsin Geological Survey, mainly covers Lake Michigan and not the Lake Superior papers. I have had the help of more recent papers read before the A. A. A. S.

N. H. Winchell did some work around Green Bay for the State Survey, never properly published, of which some results will be found in the A. J. S., 1871, pp. 1 to 4.

Agassiz's "Lake Superior," 1850, is practically inaccessible outside the large libraries, and covers only the north side of the lake and the general theory of ice action.

The earlier geologists of the D. Houghton survey have some notes, and their reports, as well as those of Jackson and others in Ex. Doc. No. 5, 31st Congress, 1st Session, Message N, 1849, pp. 391–935, and descriptions by Foster & Whitney (and Desor) in their report on Lake Superior are of historic interest. Rominger, in Volumes I, pp. 15–20, IV, p. 2, and the writer in Vol. VI, Part 1, Chapter VII, add a few facts.

Dr. C. A. Davis was with Russell and hopes to continue his work. A preliminary paper by his pen has appeared in the 9th report Mich. Acad. Sci., p. 132.



UNDERCUTTING AND RECESSION OF ALGONQUIN TERRACE LEVEL AT POINT AUX BARQUES.

ice. Also here again the ice front broke up into lobes and scallops in its waning stages. The main lobes are indicated in Figure 16.

One feature of difference however, is connected with the pre-glacial topography and that is the region where the ice was thin.

THE THINLY COVERED AREAS.

The areas colored Laurentian and Archean on the geological maps of the older rocks are relatively high. The hills are often more than 1800 feet above sea level, and the general aspect is that of a series of knobs and hollows 200 to 300 feet up and down. On the other hand Lake Superior is over 1008 feet deep, and a large part of the bottom is below sea level. We have thus a protuberance on the south side of something like 3000 feet.

Moreover, just south in Wisconsin, not over 150 miles from Lake Superior, is an area which was never reached by the ice. Now what is known of ice slopes and the thickness of ice sheets would lead us to expect that over such protuberances so near to its margin the ice could hardly extend. Ice did, however, at one time or another during the various epochs of the ice age seem to have covered all the high areas, but the main ice movement rose out upon them from the low land around as a river might rise over some mound in its flood plain in time of freshet without doing appreciable erosion.

Knobs and projecting hard points, crystals for instance of chiastolite in a chiastolite schist are smoothed and polished with scratches, but not cut down to the general level of the rock.

The old weathered soil seems to have been carried off or washed away, but very little foreign material has been brought in, and large areas are composed of bare rock knobs, slopes lined with blocks of the same stuff and swamps in the valleys.

THE ICE LOBES.

The following main streams of lobes of ice have been recognized (Fig. 16) though they doubtless flowed together and merged when the ice was at its greatest advance.

1. The Lake Superior lobe: running down the main line of the lake toward Duluth.
2. The Chippewa lobe: separated from the first by the peninsula that projects out and terminates in the Apostle Islands, and on the other side by Keweenaw Point, which, however, it over rode at one time, extending into the Ontonagon valley.
3. The Keweenaw lobe: following up Keweenaw Bay, separated on the east by the Highlands of the Huron Mountains which it wrapped around and on the west by Keweenaw Point. The Keweenaw lobe and the Chippewa lobe very likely flowed together at early stages, but even then the main threads of the ice current seem to have been present. The Keweenaw lobe seems to have felt a push from the Chippewa lobe where the Copper Range is cut through by the valleys of the Ontonagon, Flint Steel and Fire Steel, etc., which deflected it to the southeast; for while the Copper Range was last very strongly overridden around Houghton and northward by ice which moved a little north of west, heavy interlobate accumulations begin just south of Houghton and from about half way between Portage Lake and the Ontonagon river south the strong and recent motion is southeastward, and moraines are piled on the southeast side of the range and drift carried in that direction. At the south line of the state Russell* found the

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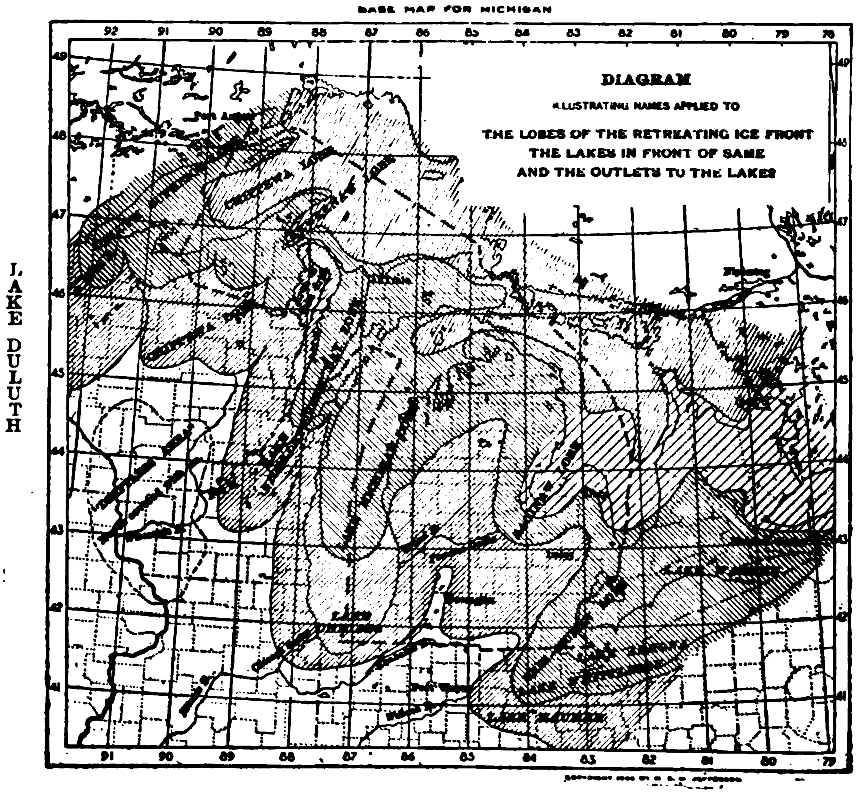
*Annual for 1906, p. 50.

dividing line between the blended Chippewa-Keweenaw lobes (which laid down heavy moraines of gray till) and the ice from the east about six miles east of Crystal Falls and Stager. This gray till overlaps that from the east. In Wisconsin the Keweenawan lobe has not been recognized as a separate body.

4. The Green Bay lobe: This was to some extent a branch of the Lake Michigan ice, but probably, as N. H. Winchell suggested, at certain stages received some ice from Lake Superior by way of a valley running north from Bay de Noc to Au Train. With this lobe one may in a broad way include


BASE MAP FOR MICHIGAN
DIAGRAM
ILLUSTRATING NAMES APPLIED TO
THE LOBES OF THE RETREATING ICE FRONT
THE LAKES IN FRONT OF SAME
AND THE OUTLETS TO THE LAKES
LAKE DULUTH
92
91
90
89
88
87
86
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83
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49
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45
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43
42
41

Figure 16—Diagram to illustrate the naming of the lobes of the retiring ice sheet and the lakes and outlets in front of them.

all the ice that wrapped around and over the iron ranges and Huron Mountains from the east as far even as Crystal Falls, and moved into Wisconsin along the axis of Green Bay. It is separated from the main Lake Michigan lobe by the escarpment of Niagaran limestone which forms the north wall of Lake Michigan and crosses the mouth of Green Bay in a series of islands. On the steep north or west side of this scarp (cuesta) the rock drops off steeply 200 to 500 feet, though the old preglacial valley in this soft shale of the Utica and Lorraine is often filled 300 feet and more.

In the Green Bay lobe there may thus at one time or another have been a commingling of three currents, one coming down from the north, one following the lowlands north of the Niagara escarpment, while a third spilled over from the main stream of ice in the Lake Michigan valley, at the mouth of Green Bay.

It does not, however, follow so broad or well marked a valley as the other lobes, even in Green Bay, and was not so pronounced a current of ice. Though it extended as far as Crystal Falls it must have been very thin, deposited little till and early retired and was broken up into separate glaciers in the valleys.

The red color characterizing its till may be due to the red Superior sandstone in part, and also to red residual clays it picked up, and to oxidation since the ice left.

5. The Lake Michigan lobe we have already mentioned. Its westward north border followed the course of the Niagaran escarpment except perhaps a few places where preglacial valleys gave it a chance to get through.

The general arrangement of these lobes and their relations to the Lower Peninsula lobe is given in Fig. 516 of Chamberlin's geology, and also in the sketch given herewith, Figure 16.

THE FIRST AREAS LAID BARE.

It is possible that even at the greatest advance of the ice, knobs here and there may have peered through, small islands in the sea of ice, nunataks as they are called in Greenland. None have yet been found, but it is quite clear that large areas were only thinly clad with ice. As the ice front retired and drew nearer and the ice itself became thinner, they would peer through here and there and then might even serve to some extent in the winter as gathering grounds for snow and ice to replenish the tongues of ice which would remain and wind in between them. Just such features are well shown on the Menominee range, and have been described by Russell.[1] Little moraines cross the valleys that trend east and west, and once lay at the ends of tongues of ice that ran out almost at right angles to the main trend of the ice sheet. Various little lakes were formed, connected and drained by channels, now abandoned, like that at Norway described by Russell.[1]

This retreat of the Green Bay lobe was probably early in the stage of the ice retreat until it got back as far as a belt running north and south along the west side of Menominee county. This position may have been held quite persistently while the Huron Mountains were being cleared, since the elevation of the moraines here is only from 700 to 800 feet up and well marked moraines bank up around the Huron Mountains at about 1150 A. T., and the grade between would be quite reasonable. Where these moraines cross the Menominee range they are nearly 900 ft. A. T., and in the Metropolitan district over 1,000 ft. A. T.

LAKE JEAN NICOLET.

As the area only thinly covered with drift running from Iron Mountain north to and including the Huron Mountains was cleared of ice first along the front of the ice, using portions of the Peshekeme, Escanaba, Menominee, Michigamme and Menominee rivers the waters issuing from the ice on three sides worked southward, deposited those large sand plains which are so conspicuous a feature on the Lower Michigamme river and of the Menominee as far down as the Wisconsin and Michigan R. R. bridge at Fisher, and drained into the driftless area of Wisconsin or skirted the ice front till they reached a large lake of which Winnebago is but a remnant. This, Upham has called Lake Jean Nicolet. By way of the Upper Fox river reversed it emptied into the Wisconsin river at Portage, and so down to the Mississippi valley.

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[1] Report for 1906, pp. 49–53.

In view of its nearness to the extreme limit of the ice and the relatively blocked channel over which it went there is little doubt that the Green Bay lobe retired at first much faster than the Michigan lobe, and that the drainage of the thinly covered Archean area into the driftless area was well organized while yet the great lake basins were occupied with ice.

By and by the ice retired in Lake Michigan, and Lake Michigan and Lake Jean Nicolet merged, but may have been separated again by readvances. But the probabilities are that the line of moraine on the east edge of Menominee county was held pretty persistently or frequently, and would hardly be abandoned until the ice was well out of Lake Michigan, though at the same time the ice may have been retiring and clearing off from more of the highland to the north. Well marked moraines lie on the north side of Huron Mountains up to about 1150 feet A. T. Thus we may imagine Lake Jean Nicolet beginning earlier, but lasting until merged into Lake Chicago.

LAKE DULUTH.

In the meantime the ice retired from the west end of Lake Superior, and water ponded in front of the Superior lobe is called Lake Duluth. It passed by way of the Bois Brulé river and St. Croix river into the Mississippi.[*] The water level at the outlet was at its highest some 550 feet above the present lake 1150 A. T.; the sill itself, however, is only 1070 A. T. and Upham assumes it has been filled 20 feet. Allowing for the usual rise to the north this would bring the water level 600 ft. and more along the north side of the Gogebic range, and as a matter of fact we find a distinct base level and sea bench at about 1230 ft. A. T. in that region. From the D., S. S. & A. R. R. north to within less than 2 miles of the lake the general level of the country where streams have not recently cut down is over 1100 ft. A. T. Around the Ontonagon valley where pass streams through the Keweenaw range, are very well marked beaches up to 1167 A. T.,

TRANSITION FROM LAKE DULUTH.

As Lake Duluth enlarged and the ice retired and melted lower water levels would be found. But nothing below 1050 A. T., say 450 feet above the lake, could be referred to this outlet, and so far as there has been relative uplift since not even as low as this. But such uplift is believed to have occurred.

Thus while the beaches found by Lawson at 535 feet above the lake at Duluth, and at 607 feet at Mount Josephines may be referred to this St. Croix outlet, the heavier beach of the Duluth Boulevard[†] must be the last stage of this lake before a new outlet opened. By the time the ice retired from Thunder Bay and the neighborhood of Port Arthur and exposed Isle Royale, however, Keweenaw Point was exposed as a string of islands broken through by narrow straits, where now are the Ontonagon, Flint Steel and Fire Steel valleys, Portage Lake, the Allouez Gap, etc. The highest recorded beaches thence north on the north shore of Lake Superior are about 413-418 feet above the lake, 1020 A. T., and belong to Lake

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[*] Upham. Geol. Minn. II, p. 643. Bull. G. S. A., II, p. 23.

[†] (At 473 ft.); Mount Josephine (at 509.5 feet); just grazing Isle Royale, around Portage Lake, and one north on the east side of Keweenaw Point a marked feature down to 490 feet above the lake. Also down to the 500 ft. contour in the Porcupines. Wright, Ann. Rep. B. G. S., '03 and '05.

Algonquin, being at the same level as beaches north of the Sault. As soon as the ice withdrew from the Huron Mountains there was clear sailing to the Lake Michigan Basin.*

It seems probable that the outlets south through or around the Huron Mountains were very temporary, and possible that these beaches at about 500 feet or less are to be correlated with an outlet to the north not far from Port Arthur as suggested by Taylor.

LAKES IN THE ONTONAGON VALLEY.

With the retirement of the ice the water must have found its way into the valley of the Ontonagon. Yet from this area there is no outlet directly south which would serve as a channel of discharge to Lake Duluth.

To work out the retreat and separation of the Keweenaw lobe from the Chippewa lobe, would even if it were known be a matter of detail which would be tedious and out of place in this preliminary sketch. The interlobate area of heavy drift which comes to a sharp point in the great kame hill of Wheal Kate, (1508 A. T.) which overlooks Portage Lake on the south, broadens as we go south, and its eastern limit follows Houghton county. No doubt along the south line of the state, between the Menominee and Montreal rivers a large area now full of lakes was once even more so, and head waters of the Black, Presque Isle and Ontonagon rivers once found their way southward. In this area, as in other such areas lying like eddies between the main channels of ice, the ice was relatively stagnant, and as it retreated huge masses were left swathed in gravel which melted only slowly and left basins without outlets, which are sometimes of large size.†

But the Keweenaw lobe, deflected by the Ontonagon spur of the Chippewa lobe hung, as we have seen, more persistently to the west side of the first opened, thinly covered area than did the Green Bay lobe to the east side, and when it retired still kept its side against the Huron Mountains, which are flanked by a crowded series of lateral terminal moraines, till terraces. Thus when the Ontonagon spurs of the Chippewa lobe retired so as to let the waters of Lake Duluth in on both sides of the Keweenaw range there seems to have been no drop of the lower Lake Duluth waters. The lake clay plains around Mass City are but little below the Boulevard Beach level.

South of the Copper Range there must have existed at one time lakes, early extensions of Lake Gogebic, whose water levels were considerably higher than Lake Duluth, and their drop may have been the other way. They may have dropped to the level of Lake Duluth. The exact point and stage of blending remains to be made out. It is west of T, 50 N., R. 40 W. We may thus be sure that during its closing stages Lake Duluth was held by the ice on the one side on the shore not far north of Isle Royale, and on the other side on the Huron Mountains, while the ice front may very likely have touched and been cleft by the northeastern ends of Isle Royale, and Keweenaw Point. When it retired further north other outlets may have been opened over the water shed into the Hudson's Bay region as suggested by Upham and Lawson.‡

---

*The higher lake terraces on the north side of the Huron Mts. are at 835 ft., 840 ft., 860 ft., levels, and correlate with Goldthwait's highest Algonquin shore line, which is found at the same level well marked just south of Newberry and at intervals on the hills beyond. But the valley that runs from Lake Superior over to Green Bay is a good deal lower than this, and would naturally have served a short time as an outlet channel as suggested by Winchell.

†Notably in the Perch Lake Topographic Sheet at the corner of Baraga, Houghton and Iron counties.

‡20th Ann. Rep. Minn. Geol. Sur., pp. 288–289. Height of Lane Portage south of Long Lake, 1102 A. T. Northeast of Michicipoten Harbor, 1042 A. T.

More careful examination of the Huron Mountains may yet disclose enough of a spill way from the west side to the east somewhere to justify treating the lake on the west as a separate unit.* It is probable that there was open connection across by Au Train to Lake Michigan before it opened farther east. This is suggested by the striking fact that back of the Pictured Rocks, within a few miles of Lake Superior, the drainage is toward Lake Michigan. It seems, too, that this channel had been kept so clear as an outlet for discharge from what was left of the Green Bay lobe that there was no material difference in the level at the two ends, and thus no separate beach lines for this part of Lake Superior. Of course something depends on what has been the tilting since.

THE WESTERN END OF LAKE ALGONQUIN IN LAKE SUPERIOR.

The highest levels that we must refer to this lake are Lawson's on the north side, 1018 A. T.† and they presumably slope off to the southwest, until they make a series of terraces of from 210 feet to 380 feet‡ above the lake which are well marked along Keweenaw Point. As Goldthwait makes it out Lake Algonquin seems to have had at one time or another three outlets, and the partition of these beaches among them is a problem of the future. So is the question how the ice influenced their altitude.

There is a fine delta of Dead river near Marquette at Forestville, and others of Swedetown and Huron Creeks near Houghton, belonging to Lake Algonquin. The Algonquin series of beaches is divisible into two series along the Michigan shore of Lake Superior, a higher one 326 to 200 feet above the lake, and a lower, probably more nearly horizontal, whose heaviest building and cutting seems to have been at about 137 ft. above the lake, and may be the Fort Brady group.

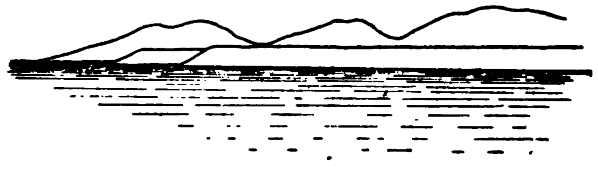

Fig. 17. The Porcupine Mountains from the mouth of Black Rivers.

The lowest level that can certainly be assigned to Lake Algonquin is the very strong shore line which, beginning just a little below 100 feet above the lake is a most marked feature all along Keweenaw Point,§ and Isle Royale as well (Fig. 17). This runs so level that we may be sure the depressing effect of the load of ice was far removed and the topographic base levels at 150 to 100 feet are so pronounced that we may be sure that the stay of the water at this level was relatively long.

---

*My examination of the north slope of Huron Mountain would indicate water levels there not above 935 A. T., and stronger at about 860 A. T. Such levels might well be those of Lake Algonquin.

†Jack Fish Bay, 418.3 A. L. Compare Sault Ste. Marie, 413.9 A. L., Mt. Josephine, 413.3, Isle Royale, 380 A. L., Thunder Cape, 392.3 A. L., Beaver Bay, 313.9 A. L.

‡Mt. Josephine 226 to 313 A. L., Lawson. Isle Royale 203 to 315 A. L., Vol. VI, p. 190. Valley of Flint Steel 335′ A. L.

§Foster & Whitney, Part 1, p. 105, 95′. Figure; Gordon, Ann. Rep. 1906, p. 420, 100′ in 1904. Figure; Wright, Ann. Rep. 1903, p. 38, 100′; Rominger, IV, p. 2, 85′ at Marquette; Jackson's report; the plates of cross sections of Porcupines, near p. 897, show the 500–600′ level, and the 100–150′ level also; p. 885 Hubbard; Lane Volume VI, Part I, p. 191, 192, most marked level 137′.

Less than 100 feet above the lake and above the heavy beach assigned to the Nipissing which is generally not over 63 feet above the lake, a couple of beaches* are sometimes noted which may perhaps be attributed to the transition time when the Nipissing outlet was just opening.

THE EARLY LAKE SUPERIOR.

When the ice retired so far that the outlet by way of North Bay, Lake Nipissing and the Ottawa river opened there was probably a rapid drop of 30 feet or more, which might have left Lake Superior separate, but as the rise of the land to the north continued until the Port Huron outlet came into play once more there soon came a time when Lake Huron and Lake Superior once more connected freely at the Sault.

This period of rise of water upon the shore would be checked when the Port Huron outlet came into play, and turned into retreat of the water, for the northern part of the lake at least, and when the sill at Sault Ste. Marie rose so high that it fixed the water level, if the tilting still continued the water would still continue to retreat on the north shore while the south shore would be submerged. Thus for the Michigan shore we may imagine the water rising, falling a little and then rising again.

The drowned character of the mouths and lower valleys of many of the rivers on the south side of Lake Superior is well known.† The excavation of the drowned river valleys may well have begun immediately at the close of Lake Algonquin, and have been interrupted by the rise of Lake Nipissing. The highest Lake Nipissing level is 49 ft. above the lake 651 A. T., at the Sault, 672 ft. A. T. at Sugar Island, about 663 feet,‡ around Port Arthur and Isle Royale and thence declines southward, the strongest work along the Michigan shore being at 25 to 30 feet. That the rise of this level was fairly slow is shown by the heavy filling at Au Train Bay, and along the north side of the Huron Mountains up to about this level, and the shore line cut by it was also recognized and mapped by the surveyors of the first Michigan Survey. Along the west shore of Keweenaw Point only patches of the bluffs cut at the high stages of Lake Nipissing, and the terrace flats in front of them have been left by later erosion but Freda Park, the outing place of the copper country, is one of them. The filling in at the head of Keweenaw Bay, where the D. S. S. & A. R. R. runs on a Nipissing terrace for six or eight miles, is conspicuous. The delta of Dead river back of the Powder Works north of Marquette, the site of Munising and the Sault are other notable features.

If, as seems probable, the sill at Sault Ste. Marie has cut but very little since that outlet was last established, and the direction of tilting is such that the Michigan shore is not at present rising as fast as that outlet, then it follows that all work at the higher levels than that which the lake can now reach in high water at stages of storms, say 15 feet or so above the mean lake level should be referred to Lake Nipissing shore lines, the work at about 30 feet above the lake particularly.

---

*Between 85' and 75' above the lake; Goldthwait and Leverett make the Nipissing on Sugar Island at 672'.

†Dead River, near Marquette, note the name. Black River, Annual for 1906, p. 160. Annual for 1903, p. 37.

‡61.3, Lawson.

INDEX.

A. Page.

Adrian, Defiance moraine, 127
  Maumee beach, 127
Advance, Ice age, 98
Aftonian interglacial interval, 120
Agriculture, surface geology, 97
Algoma beach, 134
Algonquin beaches, 110, 132–134, 136
Allegan county, sand plains, 123, 125
Allegan, soil survey, 97
Alma, soil survey, 97
Alto, ice front, 125
Ann Arbor, beaches, 136
  Defiance moraine, 127
  folio, surface geology, Lower Michigan, 97
  Illinoian drift, 121
  Maumee beach, 127
Arenac county, Lake Arkona, 128
Arkona beaches, 128, 130, 136
Au Train, Green Bay lobe at, 138
Average thickness of drift, 101

B.

Bad Axe, Belmore beach, 130
  Forest shore lines, 131
Battlefield beach, 133
Bay county, beaches, 132
  shore line, 136
Bay de Noc, Green Bay lobe in, 138
Belmore beaches, 129, 130, 136
Birmingham. Belmore beach, 130
Black river, lake beaches near, 123
Bog iron ore, 112
Bog lime, 109
Bois Brule river, outlet Lake Duluth, 140
Boulders, 107
Branch county, bog iron ore, 112
Bretz, J. Harlan, surface geology, 97
Buchanan interglacial interval, 120
Buffalo, Lake Arkona, 128

C. Page.

Calumet 40-foot beach 123, 124
Canals, surface geology 98
Carbon dioxide, effect on ice age at 100
Cass County, road gravel 109
    soil survey 97
Cedar Springs 125
Cement factories, surface geology 97
Chamberlin, T. C., surface geology 97, 102
Champlain sub-stage 120
Changes now taking place, in shore lines 135
Chara family, bog lime 109
Charlevoix, Nipissing beach at 134
Chippewa lobe 137, 141
Clay industries 97
Clyde clay 113, 115
    fine sand 115
    fine sandy loam 113, 115
    gravelly sand 113, 115
    gravelly sandy loam 115
    loam 113, 116
    sand 113, 116
    sandy loam 113, 116
    silt loam 113, 116
    stony and sandy loam 113, 116
Cole, L. J., on St. Clair flats 110
Cooper, W. F., references to 97, 101, 129, 132
Copper Range, lakes south of 141
Credner, H., walled lakes 104, 106

D.

Dams and surface geology 98
Davis, C. A., peat 108, 110
    surface geology 97
Dead river, delta of 142
Defiance moraine 128
Deltas, of Lake Algonquin 142
Deposits, of Ice Age 102
Desplaines river, glacial lake outlet 123
Detroit, beaches near 136
Dias Hill, kame 125
Drift, average thickness 101
Drumlins 102
Duluth, beaches 140
Dune sand 110, 111
Dunkirk series 113

E.

Earlier Wisconsin glacial epoch 120
East Olive, dune sand 111
East Paris, hill 125

Page.
Eaton Rapids, Grand river 126
Elkton beach 130, 132, 136
Englishville, ice retreat 125
Eskers 103

F.

Fairchild, H. L., beaches 130, 132
Flint river drainage 127
Forest beaches 130, 131, 136
Forestville delta, on Lake Algonquin 142
Fort Brady beaches 133, 142
Fort Wayne outlet 126, 127
Furnace linings, dune sand 111

G.

Gem river, glacial drainage 125
Gilbert, G. K., on tilting of Great Lake basin 135
Glacial lakes 122
Glacial rock flour 104
Glacio-lacustrine sub-stage 120
Glenwood beach 123
Goldthwait, J. W., surface geology, glacial lakes 97, 123, 132, 134, 142
Gordon, C. H., walled lakes 106
Grand Rapids, ice retreat near 125
    road gravels near 109
    Valparaiso moraines near 122
Grand river 126, 127
Grand Traverse region, soils 113
Grassmere beaches 130–132, 136
Gravels, road 104, 109
Green Bay lobe 138, 139
Green Lake outwash plain 125
Gulf stream, cause of ice age 100
Gun Lake, moraines 125

H.

Harbor Beach, shore line changes at 135
Harbor Springs, Nipissing Beach 134
Hastings, Ice retreat 125
Hogsbacks 103
Holland, lake beach 123
Houghton, delta, in Lake Algonquin near 142
Huron county, dune sand in 111
    shore line changes in 135
Huron Creek, delta of, in Lake Algonquin 142
Huron Mountains, ice covering 139–141
Huron river 126
    Illinoian drift 121

I.

Ice advances, effects of 101

Page.

Ice age, advance and causes of 98, 100
  deposits 102
  Upper Peninsula 136
Ice lobes, Upper Peninsula 137
Ice retreat 120, 124
Illinoian glacial epoch 120, 121
Illinois ice lobe 122
Illinois river, glacial lake outlet 123
Imlay City, glacial channel 127, 128
Interlobate moraine 102
Iowan glacial epoch 120, 121

J.

Jackson, eskers 103
  Grand river 126
Jefferson, M. S. W., surface geology 97
Jerseyan 120

K.

Kalamazoo, gravel plains 125
Kalamazoo, gravelly loam 113
  muck soil 111
  river 125, 126
Kames 103, 125, 141
Kansan glacial epoch 120
Kent county, Dias Hill kame 125
Keweenaw lobe 137, 141

L.

Labrador center, ice invasion from 120, 122
Lake Algonquin 124, 132, 136, 142
Lake Antoine 105
Lake Arkona, beaches 128, 129
Lake Chicago 123, 127, 128
Lake Chicago, shells 124
Lake Dana 132
Lake deposits 108
Lake Duluth 140
Lake Erie, ice sheet 122
  tilting of basin 135
Lake Gogebic 141
Lake Huron, ice sheet 122
Lake Iroquois 132
Lake Jean Nicolet 123, 139, 140
Lake Maumee 126
Lake Michigan, ice sheet 122, 139
Lake Nipissing 133, 134, 136
Lake Ridge, Belmore Beach 130
Lake Saginaw 130, 136
Lake St. Clair, drainage 126
Lake Superior, early 143
  Lake Algonquin in 142
  lobe 137

Page.

- Lake Superior, red clays 121
  - shore line changes 135
- Lake system, recent 134
- Lake Warren 130–132, 136
- Lake Whittlesey, Belmore beaches 129, 130, 136
- Lakes, Ontonagon valley 141
  - walled 104
- Lansing, esker near 103
  - road gravels near 109
- Lapeer county, Imlay channel 127
- Later Wisconsin glacial epoch 120
- Lateral moraines 102
- Lawson, A. C., surface geology beaches 97, 140–142
- Lawton, C. D., on surface geology 97
- Leipsic stage, Maumee beach 127, 136
- Leverett, Frank, surface geology, glacial lakes 97, 121–123, 125
- Lexington, shore line changes near 135
- Lima, esker 103
- Lower Peninsula, east side, early lakes along 126
  - surface geology 97

M.

- Mackinac Island, beaches at 133
- Mackinaw City, Nipissing beach at 134
  - shore line changes at 135
- Manganese, bog deposits of 112
- Manistee beaches near 133
- Manistee, ice retreat to 123, 124
- Manistee moraine 128
- Manitowac, ice retreat 124
- Marcellus, N. Y., ice front at 132
- Marilla, N. Y., Lake Whittlesey 130
- Marquette, delta, at Lake Algonquin near 142
- Marshall gravel 117
  - loam 113
- Mason, esker 103
  - ice retreat 125
- Maumee beaches 126, 127, 136
- Meadow soils 111, 112
- Mecosta, road gravels 109
- Menominee range, ice areas 139
- Miami black clay loam 119
  - clay 113
  - clay loam 113, 119
  - fine sand 113, 118
  - fine sandy loam 113, 119
  - gravel 109, 113, 118
  - gravelly loam 118
  - gravelly sand 113, 118
  - gravelly sandy loam 118
  - loam 119

Page.

Miama sand.......113, 118
    sandy loam.......113, 119
    silt loam....... 119
    stony loam.......113, 118
    stony sand....... 117
    stony sandy loam....... 117
Michigan soils....... 111
Milwaukee, tilting north from....... 135
Mohawk outlet....... 132
Monroe county, boulder....... 108
Morainal areas, soils....... 113
Moraines....... 102
Moseley, tilting on Lake Erie basin....... 135
Muck.......111, 112
Munising, soil survey....... 97
Muskegon, ice retreat....... 124

N.

Nellist, John F., soil maps by.......112, 113
New Richmond, glacial lakes near....... 123
New York, Belmore beach....... 130
Nipissing beaches, peat....... 110
Northport, Nipissing beach near....... 134

O.

Oakland county, Huron river....... 126
Ohio river, ice extension....... 122
Ontonagon Valley, Lakes....... 141
Outwash aprons....... 103
Overisel, lake beach....... 123
Owosso, soil survey....... 97

P.

Peat.......108, 110–112
Peorian interglacial epoch....... 120
Percentage of material moved by the ice....... 101
Pewamo outlet....... 130–132
Plainfield, ice retreat....... 125
Plainwell stony loam....... 113
Point Aux Barques, shore line changes....... 135
Polishing powder....... 109
Pontiac, soil survey....... 97
Port Arthur, ice retreat.......140, 141
Port Austin, tilting....... 135
Port Crescent, dune sand....... 111
Portage Lake, Wheal Kate....... 141
Portage, Wisconsin, Lake Jean Nicolet....... 140
Portland cement....... 109
Pre-glacial history....... 98

R.

Recent deposits....... 108

Page.
Recent lake system ... 134
Red clays, Lake Superior ... 121
River silts ... 110
Road gravels ... 109
Rock flour, glacial ... 104
Russell, I. C., surface geology ... 102, 139

S.

Saganing beach ... 132
Saginaw Bay, Algonquin levels ... 134
  ice lobe ... 122
  muck ... 111
Saginaw county, boulder ... 108
Saginaw (ice) lobe ... 122
Saginaw sandy loam ... 113
Saginaw, soil survey ... 97
Saginaw valley, ice advance ... 126
  ice retreat ... 124
  moraines ... 122
St. Clair flats, recent deposits ... 108
  river silts ... 110
St. Croix river, outlet Lake Duluth ... 140
St. Ignace, beaches ... 133
St. Joseph, glacial lakes ... 123
St. Joseph river ... 125, 126
Salisbury, R. D., surface geology ... 97
Sand plains ... 125
Sangamon interglacial interval ... 120
Sanilac county, esker ... 103
  shore line changes ... 135
  walled lakes ... 106
Saugatuck sand ... 113, 125
Schizothrix, bog lime ... 109
Sheboygan, ice retreat ... 123
Shells, glacial lakes ... 124, 133
Sherzer, W. H., beaches ... 136
  surface geology ... 97
Shore line changes ... 135
Smith, C. D., notes on soils ... 97
Soil maps, list of Michigan ... 97
Soil and surface deposits ... 110
South Haven, glacial lakes ... 123
Spalding, esker ... 103
Spencer, J. W., surface geology ... 97
Sub-Aftonian ... 120
Sugar Island, Nipissing beach ... 134
Summit, glacial lake outlet ... 123
Superior clay ... 113, 117
  sandy loam ... 117
Surface deposits and soils ... 110
Swan Creek, boulder ... 108
Swedetown Creek, delta, Lake Algonquin ... 142

T. Page.

Tawas Point, shore line changes.. 135
Taylor, Frank B., cited on glacial lakes...97, 123, 141
Tecumseh, road gravels.. 109
Terminal moraine.. 102
Thunder Bay, ice retreat.. 140
Till plain.. 102
    soils.. 113
Toleston Beach..132, 133
Tilting, Great Lake basin.. 135
Toronto, marine clays.. 120
Traverse Bay, drumlins.. 102
Trent outlet..132, 133
Tunnels, surface geology.. 98

U.

Ubly outlet.. 130
U. S. Department of Agriculture, Bureau of Soils.. 97
Upham, W., glacial lakes..140, 141
Upper Fox river, outlet Lake Jean Nicolet.. 140
Upper Peninsula Experiment Station, notes on soils.. 97
    Ice Age.. 136

V.

Valparaiso moraines..122, 123
Van Wert stage, Maumee beach..126, 136
Volusia series, soils.. 113
Vriesland, lake beach.. 123

W.

Walled Lakes.. 104
Water supply, surface geology.. 98
Wheal Kate, kame.. 141
Whitney, Milton, soil surveys.. 97
Winchell, N. H., Green Bay lobe.. 138
Winchells, surface geology.. 97, 101
Wisconsin glacial epoch.. 120, 122
Wisconsin river, Lake Jean Nicolet.. 140
Woodward, R. S., on compression of the earth.. 100

Y.

Yarmouth interglacial interval.. 120
Ypsilanti, Defiance moraine.. 127
    Illinoian drift.. 121
    Maumee beach.. 127

A BIOLOGICAL SURVEY

OF

Walnut Lake, Michigan.

BY

THOMAS L. HANKINSON.

WITH CHAPTERS ON THE PHYSIOGRAPHY, GEOLOGY AND FLORA OF THE REGION BY CHARLES A. DAVIS; AND A PAPER ON THE AQUATIC INSECTS OF THE LAKE BY JAMES G. NEEDHAM.

A REPORT OF THE BIOLOGICAL SURVEY OF THE STATE OF MICHIGAN,
PUBLISHED BY THE STATE BOARD OF GEOLOGICAL SURVEY
AS A PART OF THE REPORT FOR 1907.

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1908

LETTER OF TRANSMITTAL.

Office of the State Geologist,
Lansing, Michigan.

To the Honorable, the Board of Geological Survey of the State of Michigan.

Hon. Fred M. Warner, President.
Hon. D. M. Ferry, Jr.
Hon. L. L. Wright, Secretary.

Gentlemen:—I have the honor to transmit herewith, received from Chief Field Naturalist, A. G. Ruthven, for publication as a part of the Annual Report for 1907, a report on the results of a biological survey of Walnut Lake, Michigan, by Thomas L. Hankinson and associates. This report is a contribution from the Biological Survey of the State of Michigan, which the Legislature authorized you to supervise and execute by Act No. 250 of the session of 1905. It consists of a report on the fauna (particularly the fish) of Walnut Lake, and contains much of a practical nature on the economic relations, habits and distribution of the several species, special attention being given to the occurrence of the whitefish in this lake.

This report was undertaken very largely at the suggestion of Captain Clark of Northville, with the hopes of obtaining a practical result in connection with the pure scientific treatment. We hoped to find out why whitefish flourished in this lake, what it was in the surroundings that made them thrive, so that we might know where whitefish might be successfully planted and raised.

The answer seems to be that it depends on the presence of oxygen in the deep "abyssal" part of the lake, both for the whitefish and their food, the larvæ of certain midges.

Very respectfully,
ALFRED C. LANE,
State Geologist.

LETTER OF TRANSMITTAL.

Sir:—I hand you herewith a report on the results of a biological survey of Walnut Lake, Oakland county, Michigan, by Thomas L. Hankinson and others. The principal object of the investigations upon which this report is based was the determination of the reasons why the whitefish can live in Walnut Lake, so that a basis might be had to determine in what other lakes the species could be propagated.

The zoological part of the report consists of six sections, as follows:

(1) A description of the different fish habitats in the lake, with a list of the fish found in each;

(2) A list of the fish of the lake, with notes on the preferred habitats, food and breeding habits, and economic importance of the species;

(3) A list of the animals of the lake, which have an influence upon the fish fauna;

(4) A summary of the data applying to the occurrence of the whitefish in the lake;

(5) An appendix describing the apparatus used in the aquatic work;

(6) A list of the aquatic insects of the lake, with notes on their economic importance by James G. Needham.

It will thus be seen that aside from the discovery of the environmental conditions frequented by the whitefish in Walnut Lake, the report forms an important contribution to our knowledge of the fish fauna of this lake, and of the habits of the species found there.

ALEXANDER G. RUTHVEN,
Chief Field Naturalist, Biological Survey of Michigan.

ALFRED C. LANE,
State Geologist.

CONTENTS.

Page.
Letter of transmittal 155
Introduction 161
  Acknowledgments 162
  Equipment and methods of work 162
  Nomenclature and measurements 163
Physiography and Geology, by C. A. Davis 164
  Location and description of Walnut Lake 164
  The bed-rock 165
  Glacial Geology of the region 166
  Post-glacial history of the region 169
  Marl 170
  Peat 171
  Human agencies 171
  Soils and drainage basin of Walnut Lake 172
  Physiographic features of the lake shores 172
Field stations 173
  Barren shoal type 175
  Bulrush-covered shoal type 182
  Swamp loosestrife-fringed type 185
  Marsh bay type 187
  Bulrush shoal type 190
  Swampy shore type 191
  Deep water type 192
Fish of Walnut Lake 198
  Condition of fish 199
  Species, relative numbers and economic importance of the fish 199
  Methods of fishing 200
  Annotated list of the fish in Walnut Lake 200
The Flora, by C. A. Davis 217
  Relations of plants to animals 217
  Requirements of plants 217
  Adaptation of plants 217
  Law governing plant distribution 218
  Types of water plants and their association 218
  Factors controlling plant distribution in a given lake 218
  The lake a desert 219
  Reason for zonal arrangement of plants 219
  Invariable order of zones 219
  Limits of the different zones 219
  Zones above the water level 219
  Ideal classification of the plant zones of the region about Walnut Lake 220
  Reasons for variations from the zonal arrangement 220
  The plant zones of a lake affected by the soils of the bottom 220
  Application of principles to the flora of Walnut Lake 221
  Relations of soils to zonal distribution 221
  Marl 221
  Stony or gravelly soils 222
  Black mud or impure peat 222
  Effects of aquatic and marsh plant associations on their habitat 222
  The plant zones represented in a lake 223
  The sedge zone 223

Page.
- The bulrush zone.... 224
- The pondweed zone.... 225
- The water-lily zone.... 227
- Water crowfoot.... 227
- Other zones.... 227
- Flora of the highlands.... 228
- List of plants collected at Walnut Lake.... 228

The Fauna of Walnut Lake.... 232
Summary and conclusions.... 238
Appendix I, Description of apparatus and methods of recording observations.... 240
- Collecting apparatus.... 240
- Equipment for making observations.... 242
- Equipment for making records.... 243

Appendix II, Data on stomach contents of fish taken in Walnut Lake.... 244
Appendix III, Notes on the aquatic insects of Walnut Lake, with special reference to a few species of considerable importance as fish food, by James G. Needham 252

LIST OF ILLUSTRATIONS.

Plate.
XIII. Map of Walnut Lake and surrounding region.......... End.
XIV. Map of Walnut Lake showing bottom topography.......... "
XV. Outline map of Lake, showing location of stations.......... "
XVI. Portion of Station 23, showing effect of ice on trees.......... "
XVII. Beach of Station 23, showing encroaching vegetation from the sedge zone "
XVIII. Station 32 in April.......... "
XIX. Station 32, looking east.......... "
XX. Portion of Station 32, showing zone of plant life in August.......... "
XXI. Station 49, looking north.......... "
XXII. Station 46, looking south.......... "
XXIII. Station 3, looking south.......... "
XXIV. Midges on spear house at Station 3.......... "
XXV. Similar to last, but nearer view.......... "
XXVI. Beach at Station 16, showing wave-sorted shell fragments.......... "
XXVII. Marshy shore of Station 16 in April.......... "
XXVIII. Station 6, looking south toward lake.......... "
XXIX. Station 15, looking south.......... "
XXX. Station 15, looking west.......... "
XXXI. Station 4, with No. 1 in foreground.......... "
XXXII. Station 31, in April.......... "
XXXIII. Station 31, in June.......... "
XXXIV. Station 31, showing loosestrife plants and part of lily zone.......... "
XXXV. Station 26, looking east.......... "
XXXVI. Station 26, looking north, in April.......... "
XXXVII. Station 26, looking north, in June.......... "
XXXVIII. Station 26, looking south toward lake.......... "
XXXIX. Station 26, in August, showing mass of detached crowfoot plants washed against loosestrife.......... "
XL. Station 26, showing water crowfoot blossoms.......... "
XLI. Station 7, looking southwest from lake.......... "
XLII. Station 7, looking east out into lake.......... "
XLIII. Station 41, looking south, in April.......... "
XLIV. Station 41, looking south, in summer.......... "
XLV. Station 41, looking north.......... "
XLVI. Station 41, looking southeast.......... "
XLVII. Station 54, looking northeast.......... "
XLVIII. Surface vegetation in Station 54.......... "
XLIX. Margin of pool in Station 54.......... "
L. Portion of Station 54 where black bass were found nesting.......... "
LI. Station 40, in August.......... "
LII. Station 40, in April.......... "
LIII. Station 40, plant zones near center of station.......... "
LIV. Station 40, showing plant zones.......... "
LV. Station 40, interior of swamp zone.......... "
LVI. Portion of bottom on gravelly shoal of Station 23, where fish nest.. "
LVII. Another portion of the same bottom shown in 56.......... "
LVIII. Eggs of blunt-nosed minnow.......... "
LIX. Eggs of the tadpole stone cat.......... "
LX. Eggs of the blue-spotted sunfish.......... "
LXI. *Lepomis euryorus*, living specimen.......... "
LXII. Nesting place of the long-eared sunfish, Station 4.......... "

Plate. End.
LXIII. Long-eared sunfish about nest.................................. "
LXIV. Long-eared sunfish over nest, another view of same fish............ "
LXV. Swamp loosestrife, showing drooping branches..................... "
LXVI. Swamp loosestrife, showing roots on drooping branches............ "
LXVII. Eggs of musk turtle.. "
LXVIII. Rafts of rushes, possibly made by muskrats..................... "
LXIX. Rushes cut off near water surface............................... "
LXX. Fyke net on land... "
LXXI. Fyke net set in shallow water................................... "
LXXII. Trammel net set at Station 54.................................. "
LXXIII. A haul with plant hooks....................................... "
LXXIV. Aquaria.. "
LXXV. Chironomus cases x 3.. "

LIST OF FIGURES.

Figure 18.—Diagram showing results of gas analysis.......................... 197
Figure 19.—Chironomus albistria Walker: m, the epipharyngeal comb; n, the labial border; both x 55.. 256
Figure 20.—Unknown Chironomus larva from stomach of whitefish: p, epipharyngeal comb, x 310; q, labial border, x 55.............................. 257
Figure 21.—Semidiagrammatic figure of the buccal apparatus of the larva of Chironomus viridicollis V. d. W., viewed from below, the mandibles and x, and maxillæ, y, spread out laterally, and the top of the mouth moved a little anteriorly so as to show all of the epipharyngeal armature (based on drawing by Mr. H. R. Stewart.) The line i i represents the labral margin of the mouth; the parts before it are on the front of the head, outside of the mouth; the parts behind it are in the roof of the mouth. The ill-defined fringe of fine bristles along this margin has sometimes been designated as the anterior comb. f, the penduculate palps (only their penducles are shown in Miall & Hammond's The Harlequin Fly, Fig. 16), g, frontal sensory hairs; h, h, labral or external rakers; i, i, lateral papillæ; k, epipharyngeal (or posterior) comb; l, l, epipharyngeal or internal rakers; m, m, lateral arms; n, n, anterior cross bar; o, o, U-bar; p, maxillary palpus; q, lacinia of the maxilla; r, hypopharynx; z, the labial border, heavily chitinized (in situ, the mandibles swing obliquely down against this border).. 258
Figure 22.—Gall-bearing petioles of Nymphæa advena, a, external views of the gall; the dotted circle marks the epidermal window, through which the adult emerges; b, the gall cut open, showing the larva of Hydromyza confluens within. 270
Figure 23.—The larva of Hydromyza confluens. a, side view of the whole larva; b, the caudal peritreme spine, greatly enlarged; c, posterior view of the respiratory apertures; d, the prothoracic spiracular apparatus, removed and enlarged (the mark close behind the mouth in the upper figure shows the location of this).. 271

BIOLOGICAL SURVEY OF WALNUT LAKE, MICHIGAN.

BY THOMAS L. HANKINSON.

INTRODUCTION.

The present paper is the result of a biological survey of Walnut Lake, Oakland county, Michigan, carried on during the spring and summer of 1906, from April 3rd. to August 30th. The chief purpose of the work was to obtain facts concerning the fish life, not only to find out what kinds of fish lived in the lake, but more particularly to learn as much as possible about the feeding habits, breeding habits, habitat and environic (biological and physical) relations of the species. The work while thus ecological, was also economic in nature, for if successful it should reveal some of the laws governing the occurrence and local distribution of the species studied, and thus furnish evidence of the kinds of lakes in which these forms may be planted most successfully. The investigation was made at Walnut Lake, primarily, because it was known that whitefish live and thrive there. These fish have been planted in a number of apparently similar lakes in the State by the Michigan Fish Commission, but for unknown reasons, have been unable to maintain themselves, except in a few instances. It was, therefore, hoped that a study of this lake might lead to a knowledge of the conditions which enable the whitefish to live there, and that this information would be such that it could be used in the future work of stocking inland lakes of the State with this fish.

Staff and collaborators.—The investigation was in official charge of the State Geologist, Dr. Alfred C. Lane. Professor Jacob Reighard, one of the Zoological Advisors of the Michigan Board of Geological Survey, with Charles C. Adams, at the time Curator of the Museum of the University of Michigan, outlined the general plan of the work. Professor Reighard also gave much personal oversight to the investigations while they were being carried on. The field party was in direct charge of the writer, who devoted his time to the study of the fish life of the lake. In this he was aided for a part of the season by Messrs. Ellis Michael of La Porte, Indiana, and Elmer McDonald of Lerna, Illinois, as scientific assistants, and by Joseph Peters of Detroit, as fisherman. Mr. McDonald also acted as botanical collector during his stay. The party was augmented from time to time by the following specialists, who spent limited periods working on special aspects of the problem:

Prof. James G. Needham, Lake Forest University, Insects.
Mr. Bryant Walker, Detroit, Michigan, Mollusks.
Mr. A. Franklin Shull, University of Michigan, Insects.
Prof. N. H. Harvey, State Normal College, Fresh-water Sponges.
Dr. Charles A. Davis, Ann Arbor, Michigan, Plants.
Dr. John Eastwood, State Hygienic Laboratory, Water Analyses.

Acknowledgments.—I wish to express my thanks to the following persons who most generously assisted us in the work, by actual field work, by advice, or by identifying specimens. Those who helped in the last named way have the names of the kind of specimens determined for us following their names.

Jacob Reighard, University of Michigan, Ann Arbor, Mich.
A. C. Lane, State Geologist of Michigan.
C. C. Adams, University of Chicago, Chicago, Illinois.
W. B. Barrows, Michigan Agricultural College, Lansing, Michigan.
O. W. Caldwell, Normal School, Charleston, Illinois.
T. H. Briggs, Normal School, Charleston, Illinois.
F. S. Collins, Malden, Massachusetts, Algæ.
Ellen Bach, Ann Arbor, Michigan, Characeæ.
C. A. Davis, Ann Arbor, Michigan, Seed plants.
G. N. Calkins, Columbia University, New York City, Protozoa.
J. P. Moore, Philadelphia, Pennsylvania, Leeches.
Ada Weckel, Portage, Wisconsin, Amphipods.
A. E. Ortmann, Carnegie Museum, Pittsburg, Pennsylvania, Crayfish.
E. A. Birge, Madison, Wisconsin, Daphnia.
J. G. Needham, Lake Forest, Illinois, Aquatic insects.
O. A. Johannsen, Ithaca, New York, Aquatic diptera.
Nathan Banks, Washington, D. C., Spiders.
Bryant Walker, Detroit, Michigan, Mollusks.
Alexander G. Ruthven, University Museum, Ann Arbor, Michigan, Amphibians and reptiles.
R. E. Richardson, Urbana, Illinois. A few sunfish and minnows.

I would mention especially the financial assistance given the party by Dr. A. C. Lane and Mr. Bryant Walker, for which we are duly grateful, and the kind assistance of many of the residents near and about the lake.

Equipment and methods of work.—Full equipment was furnished the party by purchase, and by loan from various institutions, and a small laboratory for indoor work was fitted up in a room in the farm house where the party secured lodgings. After the preliminary study of the lake and its surroundings, it was divided into a series of stations, or regions having peculiar sets of environmental conditions for fish. These stations were visited as frequently as possible thereafter, and each was examined to determine its peculiar biological conditions, inhabitants, and other significant features. The routine work in the field consisted principally of the study of the conditions at the different stations, but no attempt was made to give all stations equal attention, the visits to particular stations being made when weather conditions were most favorable for observation, or when some particular specimens or facts were wanted. On account of the large size of the lake it was impossible to devote a large amount of time to each station, but this difficulty was in part avoided, for as the season advanced it was noted that the established stations could be grouped under several major types, and study was focussed on type stations.

Besides the field work, much indoor work was necessary, and specimens were taken to the temporary laboratory for study, identification and preservation. All specimens which could not be identified with certainty by members of the party were sent to various specialists for identification, after being properly prepared. In the indoor work the fish were, of course, given particular attention. When the collections from the different stations were brought in, the specimens were sorted, those of each species measured and the larger ones weighed. Specimens of each species in the collection were then opened, the sex organs noted, parasites removed and preserved, and any food in the alimentary canal removed, examined, and saved for more detailed study. The study of the food removed from the fish furnished us with many clews to the habits of the various fish, their habitats, their relation to other organisms, and economic importance. In the time available not much could be done toward making exact determinations of every substance found in the alimentary canal of every specimen, even if this had been desirable in a general ecological survey of the fish life of the lake, such as was undertaken. The stomach contents were preserved, however, and have been deposited with the Walnut Lake Collection in the Museum of the University of Michigan, where they can be more carefully studied. In many cases negative data concerning food were obtained, but these are usually not significant, especially where collecting was done with the fyke-net or gill-net, since it is possible that digestive processes were active for many hours after the fish were caught. Allowance must also be made when examining the stomach content records of fish taken at a particular station, for the possibility of the individual having obtained the material at some station other than the one where it was caught.

Maps.—The lake was carefully surveyed during the winter preceding the field work, by A. A. Adams, under the direction of Professor Gardner Williams of the University of Michigan, and the excellent map, (Pl. 14), was based on this survey. A large number of soundings were made through the ice, and the bottom and shape of the basin of the lake was thus obtained. This carefully prepared map was the basis for much field work, and saved a great amount of time in the location of stations. A topographic map of the region around Walnut Lake was published by the U. S. Geological Survey, cooperating with the Michigan Geological Survey* just after the field work for the season was completed. A portion of this map is used as the base for the map of the surface geology (Pl. 13).

The soil map of the Pontiac area† was also of considerable service in the reconnaissance of the country in the vicinity of the lake at the outset of the work, and was used in compiling soil and vegetation data.

Nomenclature and measurements.—For the benefit of the general reader, and to aid the publishers, common names have been used in the body of this report instead of scientific ones, except (1) in the case of species for which no common name could be found, and (2) in the lists of the flora and fauna. In the latter, both common and scientific names are used, and the reader is referred to these sections when in doubt as to the scientific name of any species.

In all records of the length of fish, the measurements were from the tip of the snout to the tip of the caudal fin. All measurements and weights are in American units, and temperature readings are in centigrade units.

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*The Pontiac Quadrangle. U. S. Geological Survey, Washington, D. C., 1907.

†Soil Survey of the Pontiac Area, Michigan. Bureau of Soils, U. S. Dept. Agriculture, Washington, D. C., 1904.

PHYSIOGRAPHY AND GEOLOGY.

BY C. A. DAVIS.

Location and description of Walnut Lake.—Walnut Lake lies in the southern part of Oakland County, Michigan, four and one-half miles south-southwest of Pontiac, which is the nearest large town. It is a little more than a mile east of the line of the Detroit and Orchard Lake Electric Railway, which gives direct connection between the lake and Detroit, either by way of Pontiac, or more quickly by way of Farmington Junction. More exactly, it is situated in the south half of Sec. 24, and the north half of Sec. 25, West Bloomfield Township (T. 2 N., R. 9 E.). It is rather more irregular in outline than is usual in lakes of its class, and has a shore line about three and one-half miles long. The longer axis lies east and west, and is nearly a mile (in round numbers, 5000 feet) in length, and its extreme width from north to south is a little more than three-fourths of a mile (more exactly, 4350 feet). Its area is approximately 232 acres, or about one-third of a square mile, and the greatest depth found by the surveyors was 101.3 feet. Its surface lies at an elevation of 881 feet above sea level, as determined by the U. S. Geological Survey, and is 306 feet higher than the Detroit river.

The lake is beautifully situated in a district where the surface is gently undulating and mostly cleared for farming purposes, but there are sufficient remnants of the forest which formerly covered the entire region, in the form of woodlots and uncleared swamps, to give variety to the landscape, and to add to its attractiveness. The region to the north of the lake is higher and rougher than that immediately adjacent, and abounds in basins and depressions some of which are of considerable size and contain lakes, swamps and bogs in various stages of development. It may be said, in passing that Walnut Lake lies near the southern border of one of the most picturesque regions to be found in Southern Michigan, and, when its beauty is fully appreciated, is destined to become the summer home of a much larger number of people than now seek it. To the south of the lake the country slopes gently, and a few miles south becomes a nearly flat plain, the geological significance of which is pointed out below.

The hydrographic basin of the lake is relatively small. There are only three small streams flowing into it, but one of which is permanent, and that becomes very insignificant in August. These three streams all enter the lake on its north side, one at the extreme extension (Station 26, Pl. 15), and the others at the head of the wide bay at the northeastern end (Station 40, Pl. 15).

Originally the lake had no surface outlet, but about 1896 an artificial channel was dug at the western end (Station 1, Pl. 15), through a shallow valley, to a small stream which runs southeastward to the Rouge river, thus lowering the surface level several feet. It was reported by farmers of the vicinity that there was no outlet from the lake whatever until this ditch was dug; it is possible that the water found its way out from the basin by percolation through porous sub-strata, as is the case with many lakes without outlets, but there is no known evidence of this.

At present, of the entire length of about three and one-half miles of shore-line, but a half-mile along the west shore, and about a quarter of a mile on the east side, are low and marshy. These marshes vary in width from a few feet to about three hundred, the widest part lying just southwest of the outlet, covering a broad platform of marl. There are two areas of firm marl shore, each about a fifth of a mile long, one on the south side and the other along the straight part of the shore. The rest of the shore is gravelly and more or less covered by bulrushes, sedges, and similar grass-like plants, which flourish in wet places, while in a few places the sod-forming grasses of the surrounding cultivated and pasture lands come down to the water's edge, a condition which probably prevailed on a much larger part of the shore before the water level was lowered by cutting the outlet.

Between the shore and the deep part of the lake, as is shown by the contour map, Pl. 14, there is an irregular belt of shallow water less than 5 feet deep. This is 700 or 800 feet broad along the east side, but in some places along the southwestern and southern margins it is only a few feet wide. The bottom of these shallows is almost entirely marl, which thus forms a platform almost around the lake, and, in the case of the marsh at the west end, has actually filled a bay of considerable size. This marl bottom has an admixture of sand in places, but is generally quite pure, and makes a firm, clean bottom. From the outer edge of this shelf the sides of the lake basin are quite steep down to depths of from 30 to 60 feet, where the slope becomes more gradual to 75 feet, and in a number of smaller areas to 95 or even more than 100 feet. The location, relative size and shape of these deeper holes are accurately shown in Pl. 14.

The bed rock.—As determined by the records of deep wells in the adjacent territory, the bed-rock in the vicinity of Walnut Lake is rather uniformly about 300 feet, or a little more, below the surface, rising from about 500 feet above sea level near Detroit to 750 feet just north of Pontiac, while the land surface rises from about 600 feet to over 1000 in about the same distance. It has already been noted that the present surface rises much more abruptly after Oakland county is reached than in the regions to the southeast, and the same is true in a lesser degree of the rock surface, which forms a low, broad ridge, 200 feet or more high, the axis of which runs northeast and southwest; this ridge had a marked influence in determining the trend and location of the surface deposits.

The rock lying nearest the surface over most of Oakland county is the Coldwater shale, a thick deposit of generally dark-colored gray, blue, red, or green, fine-grained, thin-bedded, soft rock, often called slates by well drillers. In most places where it has been penetrated, it is found to be dry, or yields small quantities of salt water. Below this is the dark-colored, often bituminous Antrim shale, which is the bed-rock nearest the surface in southeastern Oakland county, and, immediately above it, is a light-colored, often coarse-grained, water-bearing sandstone—the Marshall sandstone—which is the rock nearest the surface in the extreme northwestern corner of the county. Full accounts of these formations will be found in the various publications of the Michigan Geological Survey.

Below the Antrim shale, and forming the upper stratum of bed rock farther to the south, are the limestones of Devonian and Silurian ages, with sandstones among those of the earlier periods. The chief interest in the bed-rock lies in the fact that from it a large amount of the material which constitutes the present surface deposits has been derived. These deposits are glacial drift, and, as it is estimated that from 50 to 90% of such drift was gathered by the ice from within a few miles of the places where it was laid down, it will readily be seen that there is an intimate relationship between the bed rock in the region passed over by the ice and the soils of the region of deposition. Moreover, a comparative study of the mineral constituents of the soil, especially of the larger rock fragments, and the rock formations of the adjacent regions, gives an accurate means of finding out the direction of ice-flow. Thus, if the ice moved across sandstone areas, it would be expected that unmodified drift of the regions of deposition would be sandy, and the soils formed from it rather poor in plant food and coarse in texture, while the larger rock fragments would be of sandstone; if shales and limestones were the chief rocks in the path of the ice, the resulting drift would be fine-grained and the soils clayey, while the boulders and pebbles would be chiefly limestones and shales, or because of the soft character of these rocks, wanting, or of more resistant materials brought from a greater distance. If the Antrim shale and Monroe limestone, both easily recognized, occur in quantity in the drift of the region north of their out-cropping over the Coldwater shale or Marshall sandstone, it is good evidence that the ice which deposited them came into the locality where they were left, from the south. Such evidence is always to be taken as incomplete, however, unless very definite, since the same rocks may occur in other directions in regions more remote, from which the ice may have brought them.

Glacial geology of the region.—The last geological epoch before the present was the Glacial, during which great ice-sheets pushed out from centers of ice accumulation in the polar regions and covered parts of what are now the temperate zones. In eastern North America, an ice sheet pushed out from the highlands of Labrador, and, at the period of its greatest development, extended across the basin of the Great Lakes as far southwest as the Mississippi river, covering the intervening regions, including Michigan. From this farthest limit, the ice sheet slowly melted back, as climatic conditions ameliorated, and finally disappeared entirely, but the retreat occupied a very long time, and was accompanied by many halts and small readvances, only the last of which left legible records. If the following facts are borne in mind, the theory of glacial erosion and deposition will be more easily comprehended. The movement of glacial ice is, in effect, a kind of slow flowage, as if the ice were a very stiff liquid, and as with other liquids the rate of movement is swifter where the slope is steep and the mass deepest. Where the rate of flow is greater than that of melting the ice advances, where less it retreats, and when the two are equal, the ice margin is stationary. The ice in its passage over the land surface removed, from the underlying rocks, the soil-covering resulting from the action of the agencies of rock-disintegration through previous ages of geological time, broke away, rounded, and pulverized fragments of these, and generally planed and polished the surface of the parts left. A large part of this eroded material, including fragments of all sizes, was picked up by the ice, incorporated in it and transported for greater or less distances, and then dropped wherever the ice melted. Much of the included material was carried to the margins of the ice, since these were the chief areas of melting, and there piled up as accumulations which generally took the form of lines of low, rounded hills, known as terminal and marginal moraines, or of flat sheets, with more or less undulating surfaces, called ground moraines or till plains. In these moraines all kinds of material from the entire region traversed by the ice are likely to be present, and, because of the transporting power of the ice, it has taken the form of a mixture of fragments of all sizes, from the finest clay to huge boulders, but with the finer material predominating. This material is technically called till, while the whole deposit, sorted and unsorted, left by the ice, is called glacial drift.

In moraines of marginal types, and less frequently in the ground moraines, were frequently included detached masses of ice, sometimes of large size, which, becoming buried in mineral debris, persisted for a longer or shorter time after the main mass had melted away, and, finally disappearing, left more or less steep-sided depressions, which, later, became lakes. The water from the melting ice, flowing both within and without the glacier, carried with it suspended mineral matter, which was deposited in places where there was slackening of the current, to form more or less extensive areas of gravel, sand, or even finer material, along the channels which the water followed. These deposits were most frequent and extensive on the morainal slopes away from the ice front, and along the valleys in which the water from the melting ice ran, and are known as glacio-fluvial deposits, and, since they were formed outside the ice, or near its borders, are important aids in showing the direction of the movement and retreat of the glacial ice sheet and its lobes.

Since the ice moved more rapidly in the deeper parts these became the axes of movement, and pushed out farther from the centers of distribution than the thinner areas; thus the ice sheet had a scalloped margin, and, in later stages, was divided into lobes or tongues, the marginal moraines of which were roughly concentric, forming a series of belts, one inside the other back to the last strongholds of the ice. It seems probable that the ice was always thinner on the highlands than in the adjacent valleys, hence disappeared first from the former, while the latter still remained local centers of movement.*

The valleys now occupied by the Great Lakes were such centers of movement, and each of them has a series of moraines more or less parallel with the margins of the present basins, extending in constantly widening lines as they are crossed from the newer to the older ones over the region adjacent to them, until they meet in confluent masses known as interlobate moraines, i. e., moraines formed by the margins of two lobes when they were close together, or in contact. Thus the ice which covered the region which lies about Walnut Lake, in the latter part of the glacial period at least, since this is the part which left the clearest record, had its primary center of movement in the Labrador highland, but came into this immediate locality from the southern part of the basin in which Lake Huron now lies, and eventually melted back into it. At the same time the country beyond Pontiac, a few miles to the north, was covered by ice, also from the Labrador center, but coming immediately from the northern end of the Lake Huron basin, pushing out to the southwest through Saginaw Bay.

The topography about Walnut Lake, with its irregular lines of low, rounded hills, numerous, undrained or poorly drained hollows and swampy valleys is typical morainal topography of a rather simple kind. The region to the northwest, covered by great masses of sand and gravel and containing numerous lakes, is a well-marked and characteristic line of glacial drainage, along which the waters of the melting ice of the two closely opposed lobes of the ice sheet found an outlet to the southwest, thence to the Mississippi valley and the sea. The sands and gravels of the area are glacio-fluvial deposits left by this drainage, as the force of the streams and their carrying power decreased. The lakes and swamps of this drainage area are located chiefly in basins left by the melting masses of ice which had become detached from the main bodies for some reason, and persisted for a sufficient time to become partly buried by the materials which the outpouring streams from the main ice masses piled around them. Several miles to the north and northwest of this drainage region is a broken tract of country which was apparently the place where the margins of the two lobes came together more closely still, and the records of each have been partly obliterated by the outwash (as the debris-laden waters are termed) from both. This complex region is succeeded still farther north and northwest by the bold and prominent moraines of the ice lobe from Saginaw Bay.

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*See report on Surface Geology, preceding this paper in this Annual Report for 1907.

A mile to the south of Walnut Lake is another but much less extensive line of glacial drainage marked by a flat belt of sandy soil, about a mile wide, extending northeast and southwest on the south side of the morainal tract in which the lake lies. On the south side of this is a narrow morainal tract which marks the halt of the ice front, while the sandy area was the line of outlet for the water discharged from it. This drainage valley is less complicated in structure and relations than the one to the north, since it received the water from but one ice margin, but otherwise it exhibits the same characteristics and, because of its simplicity, is less difficult to study. Its course is also marked by fewer and smaller depressions, of which Wing and Gilbert lakes are the most extensive.

A short distance southwest of Walnut Lake is a nearly flat, clayey district of less than ten square miles in area, which has the chief characteristics of a till plain. This forms a recess in the moraine with which it is connected and is an area in which the glacial debris was deposited in a nearly flat sheet, possibly from thick or resistant ice which persisted longer than that on either side of it.

About three and one-half miles south of the lake, after crossing the drainage valley and attendant moraine, the characteristic forms of glacial deposition abruptly disappear, and the country becomes monotonously flat, with only occasional low, symmetrical ridges of sand and gravel running for long distances across it. The highest of these ridges lies just south of, and extends along the border of, the hilly country, and others, which are more prominent, run more or less parallel with it, as the slope towards Lake Erie is traversed.

These ridges are the shore lines or beaches of a series of lakes which existed towards the end of the Glacial period, between the front of the retreating ice and the highland which had recently been abandoned by it, the water from the melting ice rising to such a height as was necessary to find an outlet to the sea, either around the edge of the ice or across some gap in the moraines. The ice sheet persisted somewhat longer in the east, in southern Ontario and in the St. Lawrence valley, than it did in its thinner western extension, and hence the early outlets of the lakes mentioned above were to the southwest, ultimately through the Mississippi valley. The level of their outlets, or spillways, as they are sometimes called, fixed the height to which the waters of the lakes rose, and the length of time for which they served to keep the water at a given level, if other things were equal, determined the strength or prominence of the resulting beaches. Thus it is fair to assume that well-marked beaches are the result of a much longer period of action than low and faint ones.

These old shore lines of the glacial lakes may be recognized by their close resemblance to shores of the present lakes, and consist both of cut shores, where waves and currents washed away the materials against which they struck, and of built shores, those on which the waves piled sand and gravel into long, low, usually smooth-topped ridges, very narrow in proportion to their length. The highest glacial lake is known as Lake Maumee, and three fragmental shore lines from about 800 feet down to 760 feet above sea level are attributed to this lake. The next stage below this was Lake Whittlesey, with a nearly continuous beach about 740 feet, and the lowest one within the limits of the area mapped was Lake Arkona, which formed a definite shore line about 40 feet below the last. The position of these important ancient shore lines in the Walnut Lake region is shown on the map, Plate 13, together with the names by which they are known.

The relationship of this phase of geological history to present day conditions and especially to the animal and plant life in Walnut Lake is plain, when it is understood that the drainage of the region at the present time is largely controlled by the ancient lines of drainage, and that the modern streams find their way to the sea through valleys formed by the glacial streams or by the outlets of the glacial lakes; these valleys and streams are known to be the lines of migration through which many species from the valley of the Mississippi have found their way into the Great Lakes and their tributary streams. In cases where the connection is not a direct one, as where two streams flowing in different directions occupy an ancient valley, as frequently happens, the divide between the two is commonly a swamp, in which, in times of flood, there is a complete water connection from one stream to the other, so that fish and other aquatic animals pass as freely over the divide as if it did not exist.

It is then important, in considering the origin of our Michigan lakes, to take into account also the past history of the region, and especially the glacial history, since this undoubtedly had much to do in establishing possible routes over which species of animals returned to the glaciated regions from the country south of the Ohio River, in which they had passed the long period of the ice invasion.

To particularize still further and apply the principles laid down above to the immediate district under consideration, the moraine in which Walnut Lake lies is known as the Fort Wayne moraine, and extends from the city in Indiana near which it was first studied, and from here has been traced around the lake Erie basin. This moraine is one of the last well-marked moraines formed by the Huron-Erie lobe of the ice sheet, before it shrank back to the low lands about the deeper part of the areas now occupied by Lake Huron and Lake Erie. The basin of Walnut Lake is a morainal depression, and while it is of rather irregular form for a morainal lake, and has the outline often seen in lakes occupying drowned valleys, it seems most probable that it is the mold of an unusally formed detached mass of ice, which was wholly or partly buried in the moraine by the mineral matter included in the glacier, so that it persisted until after deposition had ceased, and, later, slowly melted away, leaving a basin with steeply sloping sides, which immediately filled with water, since much of it was below the level of any outlet channel and the ground water table as well.

Post-glacial history of the region.—After the retreat of the ice the recently abandoned surface of the glacial deposits was subject to weathering, rainwash, cutting and erosion by streams, until such time as it was protected against such deformation by the growth of vegetation dense enough to cover the loose surface and check erosion. The surprisingly small amount of evidence of such change of the form by erosion in glacial deposits of the vicinity may be taken as an indication of either different climatic conditions from those existing now, for a time after the ice retreat, so that erosion tached from the main bodies for some reason, and persisted for a sufficient time to become partly buried by the materials which the outpouring streams from the main ice masses piled around them. Several miles to the north and northwest of this drainage region is a broken tract of country which was apparently the place where the margins of the two lobes came together more closely still, and the records of each have been partly obliterated by the outwash (as the debris-laden waters are termed) from both. This complex region is succeeded still farther north and northwest by the bold and prominent moraines of the ice lobe from Saginaw Bay.

A mile to the south of Walnut Lake is another but much less extensive line of glacial drainage marked by a flat belt of sandy soil, about a mile wide, extending northeast and southwest on the south side of the morainal tract in which the lake lies. On the south side of this is a narrow morainal tract which marks the halt of the ice front, while the sandy area was the line of outlet for the water discharged from it. This drainage valley is less complicated in structure and relations than the one to the north, since it received the water from but one ice margin, but otherwise it exhibits the same characteristics and, because of its simplicity, is less difficult to study. Its course is also marked by fewer and smaller depressions, of which Wing and Gilbert lakes are the most extensive.

A short distance southwest of Walnut Lake is a nearly flat, clayey district of less than ten square miles in area, which has the chief characteristics of a till plain. This forms a recess in the moraine with which it is connected and is an area in which the glacial debris was deposited in a nearly flat sheet, possibly from thick or resistant ice which persisted longer than that on either side of it.

About three and one-half miles south of the lake, after crossing the drainage valley and attendant moraine, the characteristic forms of glacial deposition abruptly disappear, and the country becomes monotonously flat, with only occasional low, symmetrical ridges of sand and gravel running for long distances across it. The highest of these ridges lies just south of, and extends along the border of, the hilly country, and others, which are more prominent, run more or less parallel with it, as the slope towards Lake Erie is traversed.

These ridges are the shore lines or beaches of a series of lakes which existed towards the end of the Glacial period, between the front of the retreating ice and the highland which had recently been abandoned by it, the water from the melting ice rising to such a height as was necessary to find an outlet to the sea, either around the edge of the ice or across some gap in the moraines. The ice sheet persisted somewhat longer in the east, in southern Ontario and in the St. Lawrence valley, than it did in its thinner western extension, and hence the early outlets of the lakes mentioned above were to the southwest, ultimately through the Mississippi valley. The level of their outlets, or spillways, as they are sometimes called, fixed the height to which the waters of the lakes rose, and the length of time for which they served to keep the water at a given level, if other things were equal, determined the strength or prominence of the resulting beaches. Thus it is fair to assume that well-marked beaches are the result of a much longer period of action than low and faint ones.

These old shore lines of the glacial lakes may be recognized by their close resemblance to shores of the present lakes, and consist both of cut shores, where waves and currents washed away the materials against which they struck, and of built shores, those on which the waves piled sand and gravel into long, low, usually smooth-topped ridges, very narrow in proportion to their length. The highest glacial lake is known as Lake Maumee, and three fragmental shore lines from about 800 feet down to 760 feet above sea level are attributed to this lake. The next stage below this was Lake Whittlesey, with a nearly continuous beach about 740 feet, and the lowest one within the limits of the area mapped was Lake Arkona, which formed a definite shore line about 40 feet below the last. The position of these important ancient shore lines in the Walnut Lake region is shown on the map, Plate 13, together with the names by which they are known.

The relationship of this phase of geological history to present day conditions and especially to the animal and plant life in Walnut Lake is plain, when it is understood that the drainage of the region at the present time is largely controlled by the ancient lines of drainage, and that the modern streams find their way to the sea through valleys formed by the glacial streams or by the outlets of the glacial lakes; these valleys and streams are known to be the lines of migration through which many species from the valley of the Mississippi have found their way into the Great Lakes and their tributary streams. In cases where the connection is not a direct one, as where two streams flowing in different directions occupy an ancient valley, as frequently happens, the divide between the two is commonly a swamp, in which, in times of flood, there is a complete water connection from one stream to the other, so that fish and other aquatic animals pass as freely over the divide as if it did not exist.

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The latter seems a strong possibility, since forests of trees of large size, with a dense undergrowth of lesser plants are reported by Russell[1] as growing not only around the moraines bordering the Malaspina glacier in Alaska, but on the debris-covered margins of the ice itself. If similar conditions existed around the border of the greater ice sheet towards the close of the Glacial Period, it is not surprising that the present slopes of the moraines do not show more considerable evidences of erosion by wash and weathering, because they do not erode if well protected by forests or other types of vegetation. If some agency had not prevented erosion the slopes would have been much flattened, the valleys would show much greater cutting, and the drainage systems of the streams would be much more completely developed than now, since, if the slopes had been bare long, storm-waters would have rushed into the valleys and created torrential conditions and very rapid stream cutting. The fact that in the adjacent country there has been extensive gulleying of cleared slopes in the comparatively short time, less than a century, that the region has been under cultivation, is to some extent a confirmation of the hypothesis that these slopes were not long in being covered by vegetation after they were left by the glacial ice.

Because of the small erosion of the surrounding slopes and the lack of tributary streams, the basin of Walnut Lake was not modified by mechanically deposited material from the higher lands around it, nor was a natural outlet ever developed, either by overflow from the lake itself or by the cutting back of the valley with which the lake is now connected by a ditch, as might have been the case if the drainage of the area had been more strongly developed. The feebly developed drainage in this vicinity must have had its direct effect upon the fauna of Walnut Lake, by keeping the fish and other wholly aquatic animals in the lake land-locked, except in unusually high water, when temporary surface overflow from the lake may have found its way through the present outlet valley to the established stream system with which the lake is now artificially connected, but never for a sufficiently long time for a channel to be cut down to the usual level of the lake.

This land-locked condition of the lake has prevented free migration of fish and other aquatic types into and from it, except at what must have been rare and very brief intervals, since longer ones must have inevitably opened up a permanent outlet as the texture and composition of the drift makes it very easily cut by water-courses when once these are established, as is to be seen along the present ditch.

Since the ice block melted from it the basin of the lake has been slightly increased in superficial area by the action of waves, wind formed currents and ice-shove in winter, and the material removed by these agencies has either been spread over the sides and bottom of the basin, or, in the case of the ice action, pushed back from the shore in the form of a low ridge just above the water-line.

Marl.—On the other hand, internal agents in the form of plants and animal organisms have been engaged in filling the basin, and have decreased its surface much more than the others have increased it. The chief modifying agent is marl, which is, when pure, a yellowish-white, more or less powdery or granular substance, often appearing like white clay, and composed of nearly pure calcium carbonate. Marl, or "bog lime," as it has been termed, is precipitated from the water of the basins in which it is found by a number of organisms, both plant and animal. Of these the plants belonging to the stoneworts (Characeæ), and the blue-green algæ (Cyanophyceæ) are by far the most important agents, while of the animals, the mollusks contribute the largest amount. The marl usually contains sufficient unbroken shells of mollusks to attract attention, so that formerly the entire formation was supposed to be made up of shells, and was called shell-marl. In no other Michigan lake known to the writer would it be more easy to attribute the formation of marl deposits wholly to mollusks than in Walnut Lake, because of the vast numbers of dead shells of certain species of snails which are heaped up on the shores of the lake (Pl. 26). The presence of extensive beds of the stonewort (Chara) in various parts of the lake, associated with other lime-secreting Algæ, and the abundance of the characteristic remains of these plants in the marl, much exceeding those of the shells, point to the real origin of the beds here, as elsewhere. The occurrence and approximate extent of the marl beds along the shores of Walnut Lake have already been indicated on another page, but it should be noted here that the size of the original basin of the lake has been decreased by just so much space as these beds occupy. A full discussion of the formation and uses of marl will be found in a former report of this Survey.[1]

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[1] Russell, I. C. Second Expedition to Mt. St. Elias in 1891, U. S. G. S. Report, XIII, 2, p. 76.

The marl beds furnish shallows with a firm, clean bottom upon which but little vegetation grows, and of a texture sufficiently coarse (about that of sand) to be adapted to use as spawning beds for some species of fish; that they are used as such will be seen by reference to the descriptions of the stations on a subsequent page.

Peat.—But little filling has been done by peat at Walnut Lake, and, so far as observed, the deposits of this substance are all superficial, being confined to those parts of the lake where the marl beds have nearly reached the surface. The beginnings of peat deposits may be seen, however, in the accumulations of plant remains as black mud, noted in the descriptions of the stations. The marshy tract at the west end of the lake has considerable peat above the marl, and seems to have been formed by the growth of much the same plants, the bulrushes and other shallow water types, as are seen in the shoal water at the present time, and as are now growing upon the marsh. Peat is formed in large quantities in the lakes of Michigan, and has converted great numbers of the smaller ones into bogs and marshes, but lakes like Walnut Lake, which have considerable deposits of marl, seldom have much peat until late in the history of the transition from lake to marsh. An extended discussion of the formation of peat has recently been published in the annual report of the Michigan Board of Geological Survey.[2]

Human agencies.—In recent years the lake and the conditions about it have, in various ways, been profoundly modified by the hand of man. The clearing away of the forest from the surrounding slopes give the winds much freer access to the water surface and increases evaporation, and the action of waves and currents along the shores during the season of open water, as well as blow the finer soil particles into the lake. At the same time a much larger proportion of the water which falls upon the drainage basin finds its way immediately into the lake, bringing with it the finer parts of the material obtained by erosion of the denuded land surface, in the form of mud and silt, and this material spreads itself along the shores and over the bottom, making the water less clear and pure after a storm than when the region was forest-covered.

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[1] Geological Survey of Michigan, VIII, Part 3, Lansing, 1903.

[2] Davis, C. A. The Ecology of Peat Formation in Michigan, Report Mich. Geol. Surv., 1906, p. 94.

It is evident also, that the silting up of the lake will go on more rapidly under present conditions than formerly, but on account of the small drainage area directly tributary to the lake, the porous surface deposits around it, and the small size of the streams flowing into it, this change is of slight significance. The artificial outlet, which is now a permanent feature of the lake, is of more importance, since it has materially lowered the surface of the lake, and decreased its superficial area. Moreover, this change must also affect the biological relations of the lake to whatever extent the opening of a passage for the free inward and outward movement of aquatic plants and animals will affect the balance of life which was established before the outlet was made.

Soils of the drainage basin of Walnut Lake.—The morainal deposits about Walnut Lake are chiefly made up, on the surface at least, of a gravelly or sandy loam, containing a considerable number of boulders and smaller rock masses. This upper layer with its contained organic matter makes up the soil, and the type found here has been named the Miami gravelly loam in a report of the Bureau of Soils of the U. S. Dept. of Agriculture.[1] This type of soil covers practically the whole drainage basin of the lake, except at the southwest side, where a somewhat finer type, the Miami sandy loam, and at the south, where a considerable tract of coarser material, the Marshall gravel, occur. These types entirely surround the lake and cover most, if not all, of the area which can be considered tributary to it, and are sufficiently porous so that they absorb a considerable part of the rainfall, which percolates to the ground water level and finds its way out into the lake. The finer particles of these soils and of the underlying till are, in considerable part, fragments of limestone, hence the percolating water becomes strongly impregnated with calcium salts, the carbonate predominating, and, finding its way into the lake through subsurface springs, is the chief source of the marl. The water draining directly into the lake over the surface is likely to contain much less dissolved mineral matter, since it does not remain long enough in contact with the rock particles to become mineralized.

The surface of the drainage area of Walnut Lake is, then, of such porous types of soils that little water runs away on the surface, most of it becoming part of the ground water, and hence a relatively small area serves to keep the water of the lake high, and the clearing and cultivation of the land has not affected its absorbing power as much as frequently happens in more compact and clayey types, where the soil, after clearing, permits very little water to soak into it. Little is known of the structure of the glacial drift of the locality, below the soil line, but from the conditions in other places where cuts have been made, it is probable that it is made up of slightly sorted rock debris, which may be irregularly and incompletely stratified.

Physiographic features of the lake shores.—In the present paper it is not possible to go into details regarding the building of the various types of shore formations to be seen along the shores of such a lake as Walnut Lake, but it may be mentioned that quite a variety of such formations occur on a small scale, and are chiefly the result of the action of ice during winter and spring, of the waves formed by the winds, of surface currents along the shores, and of plants and animals.

The primary surface currents at any time are in the same direction with the wind; and as they are due to the drift of the surface water before the wind, the latter tends to pile up the water on the lee side of the lake, from which it returns along the other shores by gravity, in its passage cutting off the ends of any points upon these and forming spits and bars in bays behind the points, or depositing the finer and lighter drift-material in the still waters of the bays. These facts account to some extent for the deposits of fine mud in all of the bays mentioned in the descriptions of the stations on a subsequent page, and for the sand spit at station 41, described beyond (page 189) and shown in Pl. 43, although direct surface current and wave action, as shown in plate 43 are perhaps the primary causes of the formation of this spit, and the direct action may always be considered as important in all cases. The combined effect of waves and currents upon the shores is, therefore, to straighten them by eroding the points and filling the bays, the latter process greatly hastened, in many cases, by submerged plants, which retard the moving water, thus causing suspended matter to drop near or on them, and act as direct contributors to the filling by their growth and decay.

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[1] Soil Survey of the Pontiac Area, Michigan. U. S. Dept. Agriculture, Washington, D. C., 1904.

The erosion effects mentioned may be seen on the ends of any point exposed to the action of waves and currents, in the coarseness of the material upon them, and in the evidences of removal of the end of the point, which will usually have a prolongation of considerable length, extending lakewards below the surface of the water. Such washed shores afford excellent breeding places for several species of fish, as noted elsewhere. After westerly winds, accompanied by showers, the westward returning currents along the north side of Walnut Lake could be traced for more than a quarter of a mile by the muddy water from one of the inflowing streams. This water instead of flowing out into the lake, as would have been the case but for the existence of the current, was turned westward immediately at the mouth of the stream and formed a well-marked belt, a rod or more wide, in the clear water of the lake, and flowed with considerable rapidity, even though no wind was blowing at the time when the observations were made.

It is apparent, also, that these currents in shallow water must move the finer organic debris along the bottom until bays are reached, when this material is swept into them and left as sediment in their quiet water, and in such places of accumulation conditions sooner or later become favorable for the growth of plants, and these, in turn, hasten the process of filling the bay. After the plants become established, the bays furnish a favorite habitat for some of the most important food and game fish of the lake.

From the consideration given above, it seems that many factors, not always taken into account, may enter into the problem of explaining biological relations in even so small a lake as the object of this study, and that logical relations in even so small a lake as the object of this study, and not only must the present history be studied, but also the past, for there may be important matters overlooked if this is not done.

FIELD STATIONS.

BY T. L. HANKINSON.

In order to be able to attack systematically the problem of the relation of the fish life to the environment, stations were established where different environmental conditions prevailed, and these places were subjected to careful study. The stations were located early in April, before the aquatic vegetation had sprung up, so that in some instances after the vegetation appeared minor differences were observed within the station areas first located. In such instances the smaller areas were designated as substations.

It is hardly necessary to state that the boundaries of the stations were rarely well defined, but merged gradually into each other.

The stations were located at the beginning of the field season, after a careful preliminary examination of the lake and its surroundings, during which many sample collections were made. The following characteristics were the chief ones taken into consideration in locating stations: (1) aquatic vegetation, (2) nature of the bottom, (3) depth of the water, (4) nature of the soil of shore and bottom, (5) topography of shore and bottom, (6) shore vegetation, (7) exposure to waves and winds.

Since collections and observations were made over the greater part of the lake, a large number of stations were established, the general location of which can be seen in Pl. 15. The head of the outlet (the landing place) was station 1, and all stations along the shores of the north half of the lake were given even numbers, while odd numbers were used along the south half. The stations at some distance from the shore, in water over 30 feet deep, were given numbers between 200 and 250.

The stations may be classified roughly under nine types as follows:

(1) *Barren shoal type.*—In stations of this type the shores are low, sedge-covered, and often marshy, and are replaced off shore by a shallow shelf (known as the shoal) which is broad, and has a bottom of pure marl, or marl and sand, and only *inconspicuous vegetation.* At the outer edge of the shoal there was usually a pond-weed zone, and that part of it which was adjacent to the shoal was included in the station in all cases, on account of its close relationship to it. The following stations were of this type: 3, 23, 49, 37, 46, 36, 16, 12, 6 and the central part of 4.

(2) *Firm shore type.*—In stations of this type the water conditions were similar to the last, but *the shore was high, firm, grass-covered, and without a sedge zone;* frequently also there was a narrow beach between the water and the shore vegetation. This type included stations 11, the eastern part of 19, 27, 45, and 44.

(3) *Bulrush-covered shoal type.*—Stations of this type differ from type 1 only in having a conspicuous *growth of bulrushes* on the shoals. It includes stations 15, 35, 24, 20, and the western part of 19, and the northern part of 4.

(4) *Swamp loosestrife-fringed type.*—In this type, the shoals had black bottom soils and abundant luxuriant aquatic vegetation, including a water-lily zone. The shallow water on the shoreward border had a distinct *fringe of swamp loosestrife.* There were but two stations of this type, 31 and 26.

(5) *Marsh bay type.*—This type included two small bays *with very abundant aquatic vegetation,* and a shoreward border of sedges and bulrushes growing in several inches of water. From each of these bays a ditch extended back into the adjacent marsh. Stations 7 and 41 were the only ones of this type.

(6) *Bulrush shoal type.*—The extensive area of shallow water between the island on the east side of the lake and the main shore, constituted station 54, the only one of this type. The bottom of this area was densely covered by bulrushes, flags, and many other species of plants.

(7) *Swamp shore type.*—Station 40 was the only one of this type. It was peculiar in having a *wide swamp along the shore,* and a broad shoal with an abundant growth of aquatic plants, forming complex associations.

(8) *Outlet head.*—This station included the first thirty or forty feet of the outlet, or that part of it in which lake conditions were prominent.

(9) *Deep water type.*—This type comprised all stations at which the water

was over thirty feet in depth. The bottom was usually soft and oozy, and there was little, if any, except microscopic vegetation. Stations numbered from 200 to 250 were of this type.

BARREN SHOAL TYPE.

Station 23 is a good example of the barren shoal type. It extended for about a quarter of a mile along the south shore, just west of the entrance to the bay. In this station were included the woods bordering the shore as well as the zone of pond-weeds which marks its lakeward border, for the reason that they probably determine, to a considerable extent, the fish fauna of the shoal. Altogether the station had five zones (of which three were terrestrial) with peculiar environic conditions. These zones were as follows: (1) the timber zone, (2) the sedge zone, (3) the beach or shore, (4) the barren shoal, and (5) the pond-weed zone off shore.

The timber zone was the remnant of the former forest cover, and occupied an untillable portion of the bank of the lake, partly swamp and partly steep slope, and was less than a hundred feet in width. The tree growth was sharply limited towards the lake by a ridge formed by ice shoving the soil back from the shore during its expansions in winter, and possibly also by the water in spring. Evidence of the effects of the ice movement is shown by the inclination away from the lake of many of the young trees on the shoreward border of the woods, as is shown in Pl. 16.

The chief effect which the tree zone had upon the fish life of the lake was in harboring insects which may furnish a considerable amount of fish food. In the latter part of April, for example, adult midges, whose young life stages are passed in the lake and form a large part of the food of the white fish, as well as other species, were present in dense swarms in this wooded area, while they were nearly absent from the more open places. It is probable also that other insects, breeding and developing in the trees, are at times blown into the water, where they are taken by the fish.

The sedge zone extended the entire length of the station, covering the shore from the high water level to the woods, and even invading them to some extent.

During the late summer months the water receded from the lakeward margin of this zone leaving it bare. The conspicuous plants of this area, besides the sedges, were a species of horse-tail and the common lake bulrush; the latter was common at the east end of the station, encroaching on the beach, which was here low and wet (Pl. 17). Grasshoppers were abundant in this sedge-covered area in late summer, and the plants served as resting places for the adult stages of a number of aquatic species, thus making the zone a source of food supply for the fish inhabiting the waters of the station.

The beach was a narrow zone between the water and the sedge zone. It was bare during periods of low water, especially during the latter part of summer, and was most distinct in the eastern half of the station (Pl. 17), although at the eastern end for a short distance, the shore was low with shallow pools of water scattered over it. In general, however, the beach was well above lake level, and had an evident slope to the water. Along most of the zone, plants of the sedge zone were advancing towards the water by means of their underground stems, and but for the violence of the waves created by north and northwest winds, the entire beach might be covered by vegetation. During times of strong wave action, however, sedge plants were frequently found in the process of being washed out, and where a dense growth reached the water, masses of plants were often torn loose and moved along the shore by the waves. At the low point of the beach mentioned above, the bulrushes formed a thin growth over the entire area, while the wet soil had numerous plants of Chara, and of a small pond-weed with broad leaves, growing upon it, the vegetation thus being very similar to that of the adjacent shoal. The soil of the beach was composed of marl, small fragments and gravel, sometimes thoroughly wave-sorted, and in places of mixed small boulders and cobble stones (see plates 16 and 17). The only part of the beach where animal life, which could be counted as a source of food supply for fish, was at all abundant, was the low, wet, east end. Here during the latter part of August many young green frogs were seen, while tadpoles were common in the shallow water near by. The dry part of the beach seemed to have few inhabitants except small flies, spiders and toad-bugs, but it was often visited by the killdeers and the spotted sandpipers and occasionally by a yellow-legs.

The shoals proper averaged about 100 feet in width out to where the water reached a depth of four or five feet, at which depth it merged into the zone of dense pond-weeds; it was broadest at the east end, where it was 200 to 300 feet wide, while near the center it was not more than 60 feet. In this zone the bottom is covered with marl mixed with sand, gravel, and small cobble stones. Sand was abundant on the western part of the shoal, where the bottom is quite hard, while the gravel was more uniformly scattered over the east half (Plates 56 and 57).

There was little noticeable vegetation in this area, although during the summer the bottom was covered with the stonewort which grew an inch or so high. Bulrushes were scattered over the entire shoal, and increased in abundance towards the end of the season. They did not, however, form a distinct zone, although a tendency to do so was shown by the denser patches at the east and west ends and the poorly defined one near the center. The fauna of this shoal was large compared with that of the others, and the presence of pebbles and small stones on the bottom seemed to furnish favorable conditions for the inhabitants. Under these, numerous crayfish excavated hollows indicated in the small heaps of soil which they left in front of the holes. The stones also served to shelter many flat-bodied larvæ of the May-fly (*Heptagenia sp.*), leeches, masses of leech eggs, planarians, and small crustaceans. Three species of fish, the Johnny darter, miller's thumb, and blunt-nosed minnow also placed their eggs on the under sides of flat stones in this area, as has been noted in the discussions of these species on subsequent pages. During late May and early June, schools of blunt-nosed and straw-colored minnows, the former predominating, were common over this shoal, especially at the eastern end, where there was a considerable area of water only two or three inches deep. Some individuals of this species were noted at all times where the bottom was gravelly, but they were frequently absent from the places without stones. Perch also were often seen in this area, especially at night, possibly searching for crayfish, which are chiefly nocturnal in their habits. The other species of fish seen here were the black bass and sunfish, which were frequent in the latter part of May and early June, and the blue-gills, which used the deeper places for nesting. Two very different types of animals were sufficiently abundant near the deeper lakeward margin of the shoal to be mentioned, viz., a large fresh-water mussel, or clam, which was especially common near the pond-weed zone, and a colonial protozoan, *Ophrydium versatile* O. F. M., which at times completely covered the bottom of parts of the shoal, with large, greenish, gelatinous colonies.

Table of Temperatures obtained at Station 23.

Date.	Time of day.	Direction of wind.	Velocity of wind. Ft. per min.	Air temp.	Water temp.
May 16	10:00 A. M.	W.	332	27.5° c.	16. ° c.
May 18	3:40 P. M.	W.	Slight.	24.	17.5
May 23	10:30 A. M.	No wind.	....	23.	20.
June 9	9:00 P. M.	No wind.	....	22.5	21.8
June 10	9:00 A. M.	W.	898	21.2	22.6
June 19	10:15 A. M.	E.	580	25.	24.5
June 20	2:20 P. M.	N. W.	192	24.9	22.
June 24	9:30 A. M.	N. W.	360	21.2	23.
June 25	3:00 P. M.	....	142	25.5	25.5
July 5	4:30 P. M.	N. E.	822	19.9	23.8
July 6	4:30 P. M.	N. E.	337	25.2	25.
July 19	10:30 A. M.	S. E.	152	29.5	26.3
Aug. 17	5:50 P. M.	E.	67	26.5	25.5
Aug. 22	2:45 P. M.	N. W.	350	31.	30.5

Whenever this shoal was visited air and water temperatures were taken, the latter in several places where the water was about a foot deep. The readings are given in the table above, and they are too few to be of much value for purposes of generalization.

While pond-weeds were scattered over the entire aquatic part of this station, and, as mentioned above, stunted plants even occurred above the low water mark at the east end of the beach zone, in no place did they form a considerable growth in water shallower than four or five feet. In midsummer the shoreward margin of the pond-weed zone was indicated at the surface by numerous emerged flower spikes, while lake ward the zone was limited to a depth of water less than 25 feet, and no plants were found below that depth. The width of the zone varied with the steepness of slope of the bottom, from 100 feet near the ends, to 20 to 25 feet near the middle. Fish were common in this habitat at all times, as frequent examinations with the water glass showed. The most abundant species was the perch, which was especially numerous in June, when large schools of them were noted here.

Station 32 is of the same type as the one just described, but was located on the north side of the lake. It extended east from the north bay for about a third of a mile, to a point where the shoal becomes very narrow and the shore turns abruptly to the northeast. As in station 23, there was a broad sedge zone, and, in seasons of low water, a distinct broad beach. The sedge zone terminates landward at the foot of a low bluff which is tree covered, forming a lakeward edge of a woodlot (Pl. 18). These woods in spring were the gathering place for great swarms of adult midges. At high water, plants of the sedge zone grow down into the margin of the water, but at the low water period there is a broad strip of pebbly beach mostly without vegetation. As noted in connection with station 23, many insects, especially grasshoppers, live in the sedge zone, and, falling into the water, become available as fish food. The relations of the shore zones at this station are shown in Plates 19 and 20. The shoal out to a depth of four or five feet, was about a hundred feet wide at the widest part, but was much narrower in other places. The bottom of the shoal was marl, with a little gravel in the shallower places, and supported little vegetation, except the small form of stonewort found at station 23. The only other exception was a small patch of bulrushes at the east end, which enlarged as the season advanced, and was called substation A.

The animal life was not as abundant on this shoal as on the south side of the lake, but leeches and amphipods were taken, and in the middle of April pupæ of the midges were very abundant upon the water surface, while the larvæ of the same insect were often dredged from the shoal bottom. On August 6 many small univalve mollusks were seen near the shore in very shallow water (but a fraction of an inch deep). These proved to be *Limnæa desidiosa* Say, and were the only living snails found in numbers away from regions of abundant vegetation. Minnows and other small fish were often seen here in April, but were less common later in the season. The following species were taken on April 28, when fish were noticeably abundant: Johnny darter, blunt-nosed minnow, black bass (young) and *Etheostoma iowæ.* Late in the spring there were times when there would not be a single fish on the entire shoal, except at substation A, where perch, sunfish and bass were usually seen. It was evident, at all times, that this patch of rushes had more attraction for the larger fish than the part of the shoal at the west end. The accompanying table gives temperature readings at this station.

Time of day.	Wind. direction.	Wind velocity. Ft. per min.	Air temp.	Water temp. at surface.
5:00 P. M.	N. E.	248	11. °c	19. °c
3:30 P. M.	No wind.	....	18.5	17.
2:45 P. M.	N. E.	Slight.	13.5	15.
5:00 P. M.	N. E.	386	13.5	15.
11:30 A. M.	S.	468	24.5	22.5
5:40 P. M.	S.	220	21.3	22.1
8:30 P. M.	S.W.	158	25.2	21.

Station 49 is a third example of the shoal type. It lay along the southeastern shore, and included most of the broad peninsula and the bay adjacent to it on the east. The shore was low, and covered with sedges both on the wet and dry parts, although the sedge zone disappeared abruptly at the edge of the high ground, a hundred or more feet from the water. This area was very similar to the sedge zone at station 32. The soil was of the same sandy character, and there were, along the shore, small, shallow bays, in which the water was an inch or so deep. The shoal was broad, and covered with gravel and sand (Plate 21). The minnows and other small fish were generally abundant here, appearing in large schools in the shallow bays, where the temperature was much higher than in the adjacent waters of the lake. As nothing could be found in these bays which might serve as food to attract these fish, it seemed probable that they were drawn to them by the warmth of the water. On May 22nd, the following species were taken in a small seine hauled through the shoal towards the mouth of one of the bays: 105 blunt-nosed minnows, 93 straw-colored minnows, 29 barred killifish, 10 Johnny darters, 2 golden shiners, 2 least darters, 1 miller's thumb, and 1 *Etheostoma iowæ.*

This shoal was further used as a nesting place by the Johnny darters and blunt-nosed minnows.

Station 46 extended along the northeastern shore of the lake, from station

54 northward almost to station 40. Its features were entirely distinct from those already described, in having no tree zone and no extensive beach, while the sedge zone was a wide marsh, and the shoal very broad (more than 700 feet in places, see Plate 22). The shore line was broken by a number of small coves with hard, sandy bottoms, and water but a few inches deep. Between the coves were narrow, sedge-covered points.

In April and part of May large numbers of minnows and other small fish resorted to these coves and the shallower water of the shoal, but after the beginning of June very few fish were found here. About the middle of April the following species were collected here: blunt-nosed minnows, straw-colored minnows, Cayuga minnows, Johnny darters and the *Etheostoma iowæ*. On the 26th of the same month another collection was made in one of the shallow coves of the station, in water from 6 to 8 inches deep, with the following results: 100 straw-colored minnows, 80 Cayuga minnows, 75 blunt-nosed minnows, 21 black-chinned minnows, and 1 golden shiner.

Late in May, besides the minnows mentioned above, the barred killifish, common sunfish, perch and Johnny darter were taken on this shoal, making, in all nine species from this habitat. In the more gravelly places in this part of the station, crayfish made their homes under stones, as at station 23, and a Johnny darter's nest was found. It was reported also that whitefish, visited this shoal in November to spawn.

The sedge marsh at this station doubtless had a large fauna, but it could be given little attention. The leopard frog was abundant on April 26, and large numbers of frog's eggs and newly-hatched tadpoles were seen at the same time in the shallow water of the marsh. Adult midges swarmed here on this date, and the minnows caught at the time had been feeding largely upon both the pupal and adult stages of these insects.

Station 3 has been classed with the shoal type, but it differs from the stations discussed above in the fact that the shoal was much narrower, and had a bottom of marl without sand or gravel. It included about 600 feet of the west shore of the lake, south of the outlet, except for a small, shallow, rush-bordered bay, and the ditch running from it into the marsh. The bay, on account of the different environmental conditions, was treated as a distinct station, No. 7. The sedge zone of this station (3) was represented by a broad, wet marsh more than 500 feet wide at its broadest part, which was covered with a uniform growth of sedges, which grew during the early part of the season, at least, in shallow water. This station as seen from the northern end is shown in Plate 23.

In mid-April the pike used this marsh as a spawning ground, and a little earlier a school of blunt-nosed minnows were seen here, 200 feet from the main lake, which is the farthest point from open water where minnows were found during the season. Leopard frogs were numerous, and great numbers of their eggs, and later their tadpoles, were seen here. The marsh was a favorite resort for insects, and for several days, beginning April 19, midges swarmed over it by millions, especially near the lake margin. From a distance they appeared as a cloud hanging low over the marsh, and closer examination showed that the stems and leaves of the plants were blackened by resting individuals. Plates 24 and 25, showing groups of these insects on a fish house near the edge of the marsh, will give some idea of their abundance in this habitat. The shoal area of this station averaged less than 100 feet in width, and its marl bottom supported very little vegetation, except a few thin patches of bulrushes which appeared late in the season, and limited areas of small stoneworts. Almost daily observations were made at this part of the station, and it was found to be little visited by fish in the daytime, but at night, especially in April when the midges were taking flight and the pupal form was abundant on the shoal, many perch and a single whitefish were seen here. Blue-gills also used the bottom as a nesting or breeding place, building their nests in about three feet of water.

The shoal was also inhabited by crayfish, which bred here, but mollusks and larger aquatic insects were rare, if present at all. Some temperature readings were made here, and are given below with accompanying data.

Date.	Time of day.	Wind direction.	Wind velocity. Ft. per min.	Air temperature C.	Water temperature C.
April 29	5:00 P. M.	S. W.	419	19.5	8.3
April 30	11:00 A. M.	N. W.	235	17.	11.
May 1	8:00 A. M.	N. E.	740	14.	12.5
May 8	2:30 P. M.	E.	Slight.	8.5	10.5
May 19	2:30 P. M.	N. W.	340	16.	17.5

The pond-weed zone of this station was from 100 to 150 feet wide, and included that part of the bottom (from a little less than 5 feet to about 25 feet in depth) which is covered by a dense growth of pond-weeds and other aquatic plants. Here, as at other stations, the water at the outer margin of the zone was found to have a depth of about 25 feet, below which the higher plants were apparently absent. The following species of fish were taken from this area in April by means of a large fyke net: Large-mouthed black bass, common sucker, rock bass, yellow perch, common sunfish and blue-gill.

The plants of this zone are discussed on a subsequent page (225). On them were found minute snails, amphipod crustaceans and midge larvæ.

Station 16 comprised the eastern shore with the adjacent shoal and pond-weed zone of a marshy peninsula, which is about 400 feet long and 200 feet wide, and forms the east side of the bay from which runs the outlet (Pl. 27). The conditions here which can affect fish life in the lake are practically identical with those described for station 3, but the shoal is slightly narrower. The latter has a pure marl bottom, and a very scanty vegetation of dwarfed stonewort. Above the water's edge a low, firm, dry, sedge-covered ridge, either ice or wave-formed, extended the length of the station, and at the north end there was a short beach covered with bleached snail shells and their fragments, which, as shown in Plate 26, were beautifully sorted into rows by wave action. The pond-weed zone proper began in about five feet of water, although there was a scant growth of these plants in the shallower water towards the shore.

The earliest observations at this station were made on April 6th, 7th and 8th, while there was still some ice in the lake, and the marsh was frozen. At this time a few specimens of *Etheostoma iowæ*, blunt-nosed minnows and a single Cayuga minnow were taken in a dip net, as they swarmed from hiding places beneath overhanging sedge-roots, along the edge of the marsh. At this time the water temperature was nearly at the freezing point, and no fish were seen moving about on the shoal, but in spite of this, crayfish, May-fly and dragon-fly larvæ and caddice worms were found rather common in the shallow water. Plate 27 shows the part of the shore along which these observations were made, as it appeared in April.

Fish were never common on this shoal, even minnows being rather in-frequent visitors. Perch were occasionally seen at night, resting on the bottom as at other stations, and in June the north end of the shoal was frequented by blue-gills, whose nests were numerous in about 3 feet of water. A single nest each of the darter and a blunt-nosed minnow were also found here. The pond-weed zone was well-marked, and while early in the season its shoreward edge was limited by water about five feet deep, later, in July and August, the shoal was encroached upon up to about the three-foot contour, by a conspicuous growth of the characteristic plants of the zone, and scattered plants of pond-weed appeared in still shallower places. The zone extended lakeward to where the water was about 25 feet deep, below which no plants could be found. In the late summer many more fish were seen in this zone than at any other part of the station, the common species being perch, sunfish, black bass, blue-gills and minnows.

Station 6 was the west shore of the peninsula described above, with its adjacent shoal and pond-weed zone. It differed from the station just described in having no hard ridge along its shore, and in being located in a bay instead of on the open lake. The sedge marsh was wet throughout the year, and the shoal was less extensive than that on the eastern shore of the peninsula, while the pond-weed zone was broader. The station, as it appeared in early spring, is shown in Plate 28.

The marsh was apparently but rarely visited by fish, as but a single specimen, a pike, was seen in its shallow water. In early spring fish were also scarce upon the shoal, not visiting the shallow water at this time as they did in the eastern side of the peninsula. In late spring, however, minnows and darters were common here, and comparatively scarce along the other shore. The species were: blunt-nosed minnow, straw-colored minnow, golden shiner, least darter, Johnny darter, and *Etheostoma iowæ.* In July many small perch and blue-gills were seen in the shallows, and larger fish of these and other species were also observed on the shoal. During May it was a nesting place for sunfish.

As this station was located near the head of a bay, at the northern end the bottom sloped gradually from the edge of the shoal to the 25-foot line, making the pond-weed zone here unusually wide. At the southern end, on the other hand, the slope of the bottom was deep, and the pond-weed zone was consequently very narrow, only about 50 feet wide. Fish seemed usually abundant here, especially in the wider part of the zone. However, this may have been partly an apparent abundance, as it was much easier to use the drag net in this habitat. The following species were taken: Large-mouthed black bass, yellow perch, common bullhead, yellow catfish, common sunfish, blue-gill, wall-eyed pike and rock bass. Three species of turtles, the musk turtle, painted turtle and snapping turtle, were also taken in this zone.

SUMMARY.

(a) *The depth of water.* The water upon the shoal varies from less than an inch to about 3 feet in depth. The depth of water seems to have little effect on the distribution of the fish over the shoal, other than restricting the larger fish, like the black bass, sunfish and perch, to the deeper parts. The minnows kept in shallow places near the shore. This was especially true in the spring, when the minnows kept in the shallowest water in which they could swim, possibly because of food and temperature conditions.

The shallow water also was chosen for nesting by several species. Some of these were confined to certain depths, the blue-gills, for example, choosing water about 3 feet deep, apparently regardless of its relation to the shore or the pond-weed zone.

(b) *Temperature.* The effects of the water temperature on the movements of minnows is discussed in full elsewhere (p. 202), but the statement may be made here that the shallow water of the coves and lee sides of the lake was usually found to be warmest, and that the minnows sought such places, being apparently controlled in their movements by changes in water temperature.

(c) *Bottom material.* The minnows also apparently preferred stony-bottomed, barren shoals to those with marl bottom, probably because of the larger food supply in the former.

(d) *Plants.* Almost the only plants on the shoals proper were stunted stoneworts and scattered bulrushes. Their relation to fish was not apparent except at breeding time, when they afforded places of attachment for the eggs, and protection to the young.

(e) *Invertebrates.* As noted elsewhere, these shoals were the habitat of a greenish protozoan which was very abundant in spring. Crayfish were found here at all seasons. Various insects were not abundant with the exception of the midge larvæ and pupæ in April. Living mollusks were rare, but their empty shells were numerous.

(f) *Fish.* Seventeen species of fish, as listed above, were noted on the shoals of this type; the larger species were more common here at night than during the day. During the breeding season, the blue-gills kept other species from the areas in which they had their nests.

(g) *Sedge zone.* This area affects fish life more than any other shoreward zone, by furnishing a habitat for insects, which sometimes fall into the water and are eaten by fish. In spring the flooded portions are sought by the grass pike for spawning grounds, and more rarely by other species. Where these plants grow within the lake margin they furnish hiding places for numerous minnows and other small fish.

(h) *The tree zone.* Little was learned concerning its effect on the fish of the lake.

(i) *The pond-weed zone.* This was the general habitat of most of the species visiting the shoals, and all except five of the shoal fishes were also found among the pond-weeds. These exceptions were stonecat, chub-sucker, Cayuga minnows, barred killifish and miller's thumb. The pond-weed zone may be said to determine to a large extent the fish fauna of the shoals.

BULRUSH-COVERED SHOAL TYPE.

As the chief difference between stations of this type and those of the barren shoal type was one of degree rather than kind, the conditions were about identical, except for the presence of many bulrushes in the bulrush-covered shoal type. Two examples will be sufficient to show the characteristic conditions of stations of this type.

Station 15 included the small cove on the west side of the lake, between station 11 on the north and 19 on the south, a distance of about 400 feet. The shore was marshy and covered with a dense growth of sedges which reached to the water's edge. The marsh was about 100 feet wide at the ends of the station, but much narrower at the head of the cove, where woods bordered the marsh.

The shoal averaged about 20–30 feet in width, followed the curve of the shore, and was broader at the south end. The bottom was marl, and was covered by a dense growth of bulrushes (as shown in Plates 29 and 30) from the shore line to where the water reached a depth of from 3 to 4 feet. Growing with the bulrushes on the shoal, were quantities of small stoneworts and occasional pond-weeds, as in stations of the first type. From the lakeward margin of the shoal the bottom sloped abruptly to a depth of 10 or 15 feet, then less steeply to 25 feet. This area was occupied by a dense pond-weed zone, which began at the outer edge of the bulrush growth and ended in about 25 feet of water.

The fish fauna on the shoal could be, and was, studied with care, because of the ease with which it could be approached from the lake without startling its inhabitants. From early May to the middle of June the following species were seen or taken here: blue-spotted sunfish, common sunfish, blue-gill, large-mouthed black bass, perch, yellow catfish. In the early part of July schools of blunt-nosed minnows, golden shiners and very small perch were commonly seen among the bulrushes on the shoal. During the latter part of July and August this shoal, like most others, was almost deserted by fishes, except for occasional small blue-gills. The marl bottom here was used by at least three species of sunfish as a nesting place, and probably also by the black bass.

While but little attention was given to the invertebrates of the area, some notes relating to the more conspicuous types were made. Dragon-flies and damsel-flies were usually common, and underwent their final transformation on the marsh bulrushes. On May 25th a small flight of May-flies was seen, but, in July, Dr. Needham found only a few dragon-fly and damsel-fly larvæ, and characterized the zone at that time of the year as a desert so far as aquatic insects were concerned. Whirligig beetles and spiders were often seen on the surface of the water, among the bulrushes. An interesting development of minute animals was noted on August 8th, when the surface of the water among the bulrushes, and of the algæ and other plants, acquired a soot-like covering, which upon examination under the microscope was found to be made up of innumerable one-celled animals related to *Vorticella*.

The following table gives the surface temperature readings and related observations in the bulrush zone of this station:

Date.	Time of day.	Wind direction.	Wind velocity. Ft. per min.	Air temperature C.	Water temperature C.
May 4	4:00 P. M.	S. W.	482	16.5	12.
May 6	4:50 P. M.	W.	....	6.5	11.
May 9	4:15 P. M.	N. W.	....	6.	10.
May 15	11:00 A. M.	S.	Slight.	25.5	12.5
May 25	4:00 P. M.	S.	....	23.5	22.5
July 5	3:30 P. M.	N. E.	897	19.5	24.5
July 6	4:00 P. M.	E.	266	25.5	25.
July 7	2:00 P. M.	S. E.	288	25.3	26.5
July 27	4:00 P. M.	No wind.	....	20.5	24.2
July 31	3:30 P. M.	S. E.	183	26.3	27.3
Aug. 2	10:30 A. M.	E.	363	28.	25.5
Aug. 11	9:30 A. M.	W.	138	26.5	26.

The pond-weed zone does not become well defined nearer the shore than about 50 feet, or until the water reaches a depth of 5 feet, for while the pond-weed plants are present in some numbers among the bulrushes on the shoal, they do not form a dense growth except on the lakeward margin. The zone was broader than at some of the other stations described, extending lakeward nearly 200 feet. A list of the plants of this habitat is given on a subsequent page (226).

The fish fauna here was much like that of station 6. With a water-glass perch could be seen in large numbers as far below the surface as objects could be distinguished (here about 12-15 feet). Schools of minnows appeared above the submerged plants, and the Johnny darter and *Etheostoma iowæ* were frequently noted in the shallower parts of the zone. Both the gill net and fyke net were used in this area, as well as hook and line, and the following species were found to frequent it in greater or less numbers: The perch (most commonly), yellow catfish, bullhead, rock bass, common sunfish, wall-eyed pike, common sucker, whitefish, large-mouthed black bass, blue-gill. For further details concerning these catches see page 247.

Station 4 is the region included between the outlet on the west and the base of the peninsula forming stations 6 and 16 on the east. It is the shoal with its adjacent marsh and pond-weed zones. The marsh was a continuation of that of station 6, but it was somewhat narrower than that of station 6, averaging a little more than 100 feet in width. Shoreward it ended abruptly at the margin of a cultivated field, and on the lake side extended to the water's edge.

There were three sets of environmental conditions on this shoal, which differed so much as to deserve recognition as substations.

Substation a was an area of stony bottom, about 20 feet in diameter, at the west end of the shoal, probably formed by a load of field-stone dumped in here from the cultivated land near by, and possibly spread out to some extent by ice-action. Pl. 31 shows this substation in summer, after the bulrushes had grown, making conditions similar to those at substation c. Small fish were seen here whenever the substation was visited, either day or night, throughout the season, and were often abundant over the stones in this habitat when none could be found on the rest of the shoal.

Substation b was the barren middle part of the shoal. It had a pure marl bottom which was without visible plant covering, and fish were seldom seen here.

Substation c was the east end of the shoal. It had a considerable growth of bulrushes which made it like station 15. The bulrush zone was narrow here, and covered with water about a foot in depth; the bottom was marl covered with low stoneworts growing between the bulrushes; and it sloped abruptly to deeper water from the edge of the shoal. In April the following fish were taken in a net from this place: pike, perch, common and long-eared sunfish. In May and June, sunfish, black bass, perch, blunt-nosed and straw-colored minnows, the least darter and *Etheostoma iowæ* were common in this zone, and in July it was used extensively as a breeding place by the common, the blue-spotted, and the long-eared sunfish, which made their nests in water about 15 inches deep. Notes on their nesting habits are given on subsequent pages (210, 212).

The minnows and small individuals of other species were abundant about these nests, feeding on the eggs and newly-hatched young. Plate 31 gives a general view of station 4, including the beginning of the outlet. Plates 51 and 52 are snapshots of a long-eared sunfish guarding its nest at this station. The other inhabitants noted in the bulrush zone of this station were numerous midge pupæ (seen on the bottom in April), *Sialis* adults (common on April 23, as in other similar places at about the same time), crayfish (numerous on the deeper part of the shoal during the summer).

The following temperature readings were made at the water surface:

Date.	Time of day.	Wind direction.	Wind velocity Ft. per min.	Air temperature. C.	Water temperature C.
May 19	9:25 A. M.		490	20.	18.
June 28	10:30 A. M.	S..	347	25.4	25.
June 29	7:30 A. M.	S.W.	220	28.2	23.5
July 1	10:15 A. M.	N. W.	Slight.	27.	23.2
July 4	8:00 A. M.	W.	271	23.	23.

SUMMARY.

As pointed out above, the chief difference between this and the barren shoal type of station is the presence of the thick growth of bulrushes in shallow water, and since this is the only peculiarity, the relation of the plants to fish life is the only matter needing emphasis here.

From the fact that there were more large fish, chiefly bass and sunfish, on the bulrush-covered shoals during the breeding season in the spring than on those of the barren type, it was inferred that the conditions in the former habitat were more attractive to the fish than those of the latter. Four reasons for this seem to be apparent, viz.: (1) The bulrushes afford hiding places for the nests and young, as well as for the old fish during the breeding season; (2) the roots and underground stems of the plants serve as good places for the attachment of the eggs; (3) the water is less liable to be affected by strong waves where the plants are dense; and (4) these shoals are apparently better feeding grounds than the barren ones, as collections made from them indicate that the larvæ of dragon-flies, May-flies and midges, as well as crayfish, seemed more numerous among the plants than on the open shoals, except those with stony bottoms.

SWAMP LOOSESTRIFE-FRINGED TYPE.

The swamp loosestrife, which characterized stations of this type, is described at length on a subsequent page (231), and also in another publication of this Survey.* In Walnut Lake it is limited to the two areas described below, which form a very distinct type of stations.

Station 31 included a part of the west shore of the south bay of the lake and was about 300 feet long, and from 10 to 30 feet wide. It was bordered along the water's edge by a thick growth of the swamp loosestrife, which grew in water from a few inches to slightly more than 2 feet in depth. Plate 32 shows this station in April, and Plate 33 in the latter part of June.

The station had four distinct zones of vegetation. These were (named in order from the dry ground to the deep water): (1) sedge zone, (2) swamp loosestrife zone, (3) water lily zone, (4) pond-weed zone. The most conspicuous plant in each of these zones was the one which gave to the zone its name.

The sedge zone was a tract of marsh several acres in extent, and covered by several inches of water which surrounded the stools of the tussock sedge, the common sedge here.

The swamp loosestrife zone, as it appeared from the lake, is shown in Plate 34. Fish were seldom observed in the shallow water among the stools of the swamp loosestrife, and none were caught with a dip net, but on May

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*Davis C. A. The Formation and Distribution of Peat Bogs in the Northern Peninsula of Michigan. Report Mich. Geol. Surv., 1906.

30, a trammel net placed along the fringe captured three species of sunfish, the blue-green, common, and a specimen of *Lepomis euryorus*.

The relationship of the pond-lily zone to the last is clearly indicated in Pls. 33 and 34. The water in which the water-lilies grew was from two to six feet deep, and the bottom was covered by a thick growth of stoneworts and some pond-weed. According to our observations, fish were never abundant here; on June 24th some young blue-gills and black bass were noted.

The pond-weed zone extended from the lakeward margin of the pond-lily zone into deep water, and unlike the other zones of the station, had a large fish population during the summer. The principal forms were young perch and minnows. Blunt-nosed and straw-colored minnows, common and golden shiners were always noted to be abundant in the shallower parts of the zone, whenever it was visited, and were peculiarly active, darting about as if at play, while in apparently peaceable association with them were seen black bass, rock bass and perch.

Station 26, the other example of the type of station under discussion, included the north shore of the bay of the lake, and was the extreme northern station. It differed from 31 in being sheltered on three sides by wooded hills, in being only 35 feet deep at its deepest part, and but 8 or 10 feet deep for about 100 feet from the shore. There were three well-defined zones of vegetation, the sedge, swamp loosestrife, and that of wholly aquatic plants, including water-lilies. Plates 35 to 40 inclusive, show various aspects of this station.

The sedge zone lay across the mouth of a small valley, in which, during the wet part of the year, runs the intermittent stream which drains the wood-covered slopes north of the lake. The vegetation of this area is well shown in Plate 35. It lay between the swamp loosestrife zone near the margin and the shrubs that bordered the woods. Near the level of the water the plants were chiefly tall-growing species of sedges, with a small area of cattails near the east end.

The swamp loosestrife zone followed the curved shore of the north end of the bay for about 100 feet, and was from 10 to 20 feet in width. The plant grew from the place where the soil was simply moist out into the water about eighteen inches deep. No data on the interrelation between these conditions and the fish were found.

The zone of aquatic plants extended outward for about 100 feet from the lakeward margin of the loosestrife zone to a depth of from 8 to 10 feet. It may even have extended farther, since the bottom below that depth was not studied carefully. The conspicuous plants of this area differed at different times during the season; first, water lilies appeared in early summer, forming an incomplete zone, then, the white water crowfoot covered the water with its dainty blossoms (Plates 39 and 40), and later, the outer parts of the zone were occupied by several kinds of pond-weeds. The bottom in this habitat was a black mud, incipient peat, formed from decaying aquatic vegetation, and the leaves and other parts of marsh and land plants which had blown into the lake. Immediately lakeward of the swamp loosestrife zone, in water about two feet deep, was an irregular strip where the black mud was covered by undecayed water-logged twigs, leaves and other plant debris. This strip was bare of plants, except for a few stoneworts and floating filamentous algæ. The undecomposed material was probably much increased by a mass some 50 feet long and 12 wide, of stems of white water crowfoot, which in August was swept over it by wind, and became lodged against the swamp loosestrife. (Plate 39).

Large schools of blunt-nosed minnows were often seen in the parts of this zone where the vegetation was dense, and other small fish, especially golden shiners were usually found. The least darter was abundant in May and June, and probably bred here. The common sunfish used the shallow, bare area near the inner margin of the zone as a nesting place, and the shallow water of the entire station seemed a favorite resort for perch fry, in early June, and for young minnows (too small for determination) which were very abundant. Some small chub-suckers were also taken here on June 15. The musk and painted turtles were common at this station.

MARSH BAY TYPE.

Of the two stations of this type station 7 was most often visited, because it was very accessible, and because of the ease with which the large number of species of fish inhabiting it could be studied. For these reasons this station was given more attention than any other on the lake. It included the small bay, or cove, in the marsh on the west side of the lake, which was mentioned in describing station 3, and an area of yellow water-lily plants at its mouth, which was considered a part of the station, because it was the refuge of many of the fish frequenting the bay. A ditch 5 or 6 feet wide, cutting across the marsh from west to east, enters the bay. The latter was circular in form, and bordered by bulrushes and a sedge marsh. At the water's edge on the north side of the bay a group of swamp loosestrife plants were established, and another group was situated on an old muskrat house in the middle of the bay. The bulrush growth forms projecting points on either side of the bay, which nearly close its mouth, and partly cut it off from the lake. Plates 41 and 42 show the type of shore vegetation and other features of this station.

In the spring the average depth of water in the bay was about a foot, in the summer it was less than this over most of the bottom, because of the lower water level of the lake, and the dense growth of submerged plants which carpeted a large part of the area. The bottom was covered by a layer of black, soft, peaty ooze, above a different substratum, apparently marl. Many types of plants were found here, and a description of the relations of those noted during the spring will be found on a subsequent page (222). It is sufficient to say that the dense growth of vegetation at this station was never so luxuriant that it interfered to any marked extent with the fish life by restricting swimming space over any considerable area, for there were always a few inches of water over the tops of the submerged plants, besides many bare spots covered by accumulations of water-logged chips, sticks, bits of bulrushes and other coarse fragments of vegetable matter, brought here by waves and surface currents. Such a spot in the south part of the bay, having an area of three or four square yards, was covered by but a few inches of water, yet minnows were more abundant upon it than in any other part of the station.

Easterly winds drove waves of considerable height into the bay, in spite of the protecting bulrush points, and the water was sometimes turbid from this cause. This undoubtedly affected the life relations of the bay, by preventing its being clogged with aquatic vegetation.

One type of plants found in the bay, the bladderworts, may have a slightly unfavorable effect upon the fish life, by lessening the food supply of some of the smaller species. These plants are said to be carnivorous,* the bladder-like expansions on their leaves and stems serving as traps and absorptive organs for small crustaceans and other animals which may enter them. On July 5th some material from one of these "bladders" was examined, and was found to contain several minute crustaceans of the kind used as food by small fish at this station. This effect must be very insignificant, however, as the plants are few, and the bladder-like traps are only operative on such organisms as enter them.

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*Darwin, C. Insectivorous Plants.

This station was visited almost daily from about the first of May until August 15th, and, since, owing to the concealment afforded by the bulrush points, it was easy to approach the bay from either side without disturbing the fish, many very satisfactory observations were made upon their habits. Until about the middle of June full-grown specimens of black bass and sunfish were found present at almost every visit, and, as but few sunfish nested here, it is probable these species come here for food. A trammel net set across the bay at this season caught individuals of the following species: black bass, blue-gill, common sunfish, blue-spotted sunfish, rock bass and common bullhead. From the table given on a subsequent page (249) the full data regarding the food of these specimens may be obtained; it may be said here that they had been feeding largely on crayfish and the larvæ of aquatic insects.

After the middle of June large fish almost entirely disappeared from the bay, as they did from other shallow parts of the lake, but small fish were common here all the summer. During May, large schools of minnows, of which the blunt-nosed was the most common, were seen at nearly every visit to the station. With this species were associated at this time the straw-colored, Cayuga, and black-chinned minnows, golden shiner and barred killifish. In August golden shiners and black-chinned minnows were the common species, while those first mentioned became scarce. Least darters were numerous until about the middle of June, after which none were seen, while young perch, about an inch long, appeared in large numbers and were noted until the middle of July, after which few were seen. A list of important fish taken at this station will be found in the table on page (249). In addition to those given above, this list includes horned dace or chub, common sucker, yellow catfish, bullhead, tadpole stone cat, pike, rock bass, blue-spotted sunfish, wall-eyed pike, and *Etheostoma iowæ*.

The invertebrates of the station were not carefully studied, but the more conspicuous forms seen at each visit were noted and usually preserved when collected. Of these may be mentioned the red-bellied leech, crayfish, amphipods, dragon and damsel-flies in all stages of development from eggs to adults, caddice-flies, water striders, whirligig beetles *Zaïtha sp.*, back swimmers, and other insects. Further information relating to the insects of this station will be found in the report of Dr. Needham, in Appendix III, page (252).

The conspicuous vertebrates (other than fish) of this station were the large green frog, and turtles of three species, the musk, painted and Blanding. The musk turtles laid their eggs in the remains of a muskrat house near the south side of the bay. The red-winged blackbird and marsh wren were common in the sedge zone, and probably bred there during the early part of the summer, and in late summer the least bittern was noted several times. A muskrat house, apparently not inhabited, was located near the center of this bay, in a patch of loosestrife, see Plate 41.

Station 41 was the second one of this type. It comprised the small enclosed cove and the adjacent shoal located at the southeast bend of the south bay.

The general appearance of the station is shown in Plates 43 to 46 inclusive. It resembled station 7 in being a small, partly enclosed body of shallow water, into which opened a stagnant ditch cut through a marsh which forms its landward margin, and in having very abundant vegetation growing on a bottom composed of very soft, black, peaty mud. It differed from the other station in that it was not exposed to the force of strong lake waves, and in being separated from the deep water of the main lake by a broad shoal. The highest part of this shoal was a wave-formed spit which was above the water level, and projected southward to form the western side of the cove (See Plate 43.) The waves were constantly driving sand and other materials down the shore of the bay, and depositing them in the quiet water at the end of the spit, thus elongating it. Other conditions that distinguished this habitat from station 7 were the greater depth of the black mud at the bottom (more than three feet), and the greater luxuriance of the vegetation in parts of the bay, especially the northern part, where from early summer the water was completely clogged with plants of a number of species (see the following pages) which formed a dense mat over the surface (see Plate 45).

The shoal adjacent to the mouth of the bay supported a growth of bulrushes (Plate 46) on the marl bottom, out to where the water was more than three feet deep. The sand spit supported a rather sparse growth of sedge with some swamp loosestrife, as shown in Plates 45 and 46.

In April and May small fish were very numerous in the shallow water of the cove, but they became fewer as the plants grew up from the bottom and decreased the depth and area of the open water. At low water level in August the water, except for spots of floating algæ, was only about six inches deep over the plants in the south part of the cove, while in the northern part the top of the water plants formed a dense mat on the surface of the water, and there were no open areas.

A number of collections of fish were made through the season at this station, the details of which may be found on a subsequent page (250). The species taken or seen here were, pike, blunt-nosed, straw-colored, black-chinned and Cayuga minnows, golden shiner, *Etheostoma iowæ*, *Notropis anogenus*, tadpole stone cat, barred killifish, rock bass, blue-spotted sunfish blue-gill, common sunfish, large-mouthed black bass, perch, Johnny darter, least darter, yellow catfish, common bullhead.

As noted above, the April and May hauls of the nets secured many more species and specimens than those of the succeeding months. An interesting observation on biological relations was made here in August, when it was found that the small fish were again abundant in the paths which had been opened across the masses of water plants in the end of the bay by muskrats or turtles. (The musk turtles used an old muskrat house on the south shore of the station as a place for the incubation of their eggs, and on June 25th ninety eggs, in groups, as shown in Plate 67, were uncovered here and photographed.)

The only notes on invertebrates made at this station were that on April 10th, large red midge larvæ were very abundant on the marl bottom of that portion of the lake included in this station, and a week later the adult insects were numerous in the air, and pupa skins covered the water.

SUMMARY.

The two stations included in this type are alike in being small, shallow coves, with bottoms composed of soft, black mud, on which plants grow in great profusion. Each station was located in the midst of a marsh, through which a ditch had been cut, but in which water is stagnant. Station 7 was located so that it frequently received the full force of the waves caused by easterly winds sweeping across the lake open, but station 41 was free from this factor, as it was situated near the shoreward end of a protected bay, and all waves that entered it were small. Station 7 also opened into deep water, being separated from it only by a narrow shoal, while station 41 was bordered by a broad marl shoal. The greater depth and richness of mud at the bottom, and less exposure to active wave action, in station 41 permitted a denser and more thrifty growth of plants, and this, compared with station 7, limited the amount of space available for fish movements. On the whole, fish were present in greater numbers and more constantly in these two coves than in any other areas of similar size in the lake. Fish of many species and in large numbers used these stations as feeding grounds, especially the young of such important types as black bass, perch, blue-gill and bullhead. A few nests of breeding fish were found at station 7, but none at station 41.

BULRUSH SHOAL TYPE.

On the east side of the lake, 150 or more feet from shore, was a small island at low water. This island was about 200 feet long and 100 wide, but it was nearly submerged during high water, except for a small area on the south side, which is permanently above ordinary high water. The water between this island and the mainland averaged from two to three feet in depth, and only exceeded five feet along its shoalless margins. This shoal area was station 54; it had usually a marly bottom, and was covered with a more or less dense growth of bulrushes, thickest in the south half and thinner on the east end and west sides, where the stations merged into stations 46 and 49. On parts of the shoal where submerged plants grew, the marl was covered by a layer of black organic material.

This seemed to be the most important shallow water area of the lake, as far as the fish life was concerned. It is shown upon the map, Pl. 15, between the dotted lines on the peninsula marked with the station number and the shore line. The data for the map was taken while thick ice covered the area, and, with the island, this station was mistaken for a marshy peninsula. Plates 47 to 50, inclusive, show some of the characters of this station.

Stoneworts were abundantly distributed over the bottom, generally growing with the bulrushes, but one circular area of about 60 feet in diameter near the eastern border of the station was so densely covered by these plants that the bulrushes could not grow there. The stoneworts grew at least two feet high here in August, reaching almost to the surface; the open water here presented conditions so different from those where the the bulrushes grew that it was called substation 54a. A part of the margin of the clear area is shown in Plate 49.

Among the bulrushes cattails and other aquatic plants were numerous, sometimes, as in the case of the water-lilies, covering the water surface (Plates 48 and 49). The species of plants found here are given on a following page (224).

Fish were common here until the latter part of the summer, when, as in other shallow water areas, they became scarce. Large numbers of black bass used it as a nesting place in May, making their nests and laying their eggs in from 12 to 15 inches of water, but there were few young reared here.

The adults were speared from their nests by fishermen. Sunfish, on the other hand, while common, did not breed here, so far as could be determined. Other species of fish noted at the station were pike, blunt-nosed and black-chinned minnows, golden shiner, chub sucker, bullhead, yellow catfish, blue-gill and rock bass, *Lepomis eurzorus*, long-eared sunfish, yellow perch, Johnny darter, probably *Etheostoma iowæ.*

The trammel net was found most effective for catching fish at this station, and during May a number of hauls were made with it. The collections and notes made are given on a subsequent page (250). Plate 72 shows this net set across station 54a.

Next to fishes the birds were the most conspicuous vertebrates of this station, two species, the red-winged blackbird and marsh wren, being common. The blackbirds were particularly numerous, and bred among the bulrushes. When this station was visited on the night of June 12th, hundreds of these birds were found roosting on the stems of the plants. In July, large numbers of barn swallows used the bulrushes as resting places at night. Two species of turtles, the musk and the painted, were often seen; on August 1st one of the first named species was observed eating a dead black bass.

There were several muskrat houses at this station, although none of these animals were seen. Insects of several kinds were abundant, the dragon-flies and damsel-flies being the most noticeable, as they were very active when weather conditions were favorable. Late in April midge larvæ were found in collections made from the marl bottom of the station, and on May 21st adult midges of a different species from that so abundant over the marshes in April were noted on the bulrushes.

SWAMPY SHORE TYPE.

Station 40 was the only example of this kind. It was located at the northeastern part of the lake, extending about 300 feet in a westerly direction from the point (see map) where the shore bends almost at right angles, after turning northward. It included the north end of the wide northeast bay, and differed from other stations in that it supported a tree-covered swamp, and an unusual amount of aquatic vegetation.

The plant associations divided this station into four quite well-marked zones, the swamp, the sedge, the cattail and the bulrush and waterlily zones each presenting some peculiarities as a habitat for fish.

The swamp zone (Plates 51–55, inclusive) was situated on the lakeward border of a large marsh, and had a heavy growth of trees and shrubs. These plants grew in very wet soil, with pools of stagnant water, a foot or two deep, between the trees and clumps of bushes. These pools during the summer were covered by an almost unbroken carpet of duckweed (see Plate 55). Sedges and many other herbaceous plants grew among the trees and shrubs, forming a dense border in the part of the zone towards the lake.

Numerous tadpoles and three species of fish (mud minnows, young perch and brook sticklebacks) were caught in a dip net in these pools on June 16th. This was the only place where the sticklebacks were found about Walnut Lake. Plate 55 shows part of the interior of the swamp zone.

The sedge zone was distinct only in the eastern part of the station, where it consisted of a narrow belt of sedges close to the shrubs of the swamp zone. The ground here was wet throughout the season, but there was not enough water to allow fish to move in it to any extent.

The cattail and bulrush zone began at the shoreward edge of shallow water, as shown in the figures, and was really a double zone, the cattails in very shallow water, and the bulrushes extending out to depths of five feet, in places more than 200 feet from shore. Plants other than those mentioned were present in different parts of the zone, sometimes in abundance, as at the west end of the station, where quantities of a species of horsetail grew in the shallow water with the bulrushes. About the middle of the station was a small cove, where the bulrush growth was sparse and the cattail grew in small clumps; in summer the water in this cove was covered with duckweed (Plate 53).

The waterlily zone was present along the west portion of the station, and became noticeable about the last of May, at which time the floating leaves of the lilies appeared. At the west end of the station these plants extended out from shore for some 200 feet to the edge of the broad shoal.

The shallow water of this station was frequented by many species of fish, and numerous individuals were seen at every visit made when conditions were favorable for observation. This station was not visited regularly, however, and, because of the rank vegetation over much of its area, but little collecting could be done. According to observations, the large fish, like black bass and sunfish, were common on this shoal, as upon the others studied, only during the spring and early summer, although sunfish nested here in shallow water. Minnows abounded both in the spring and summer, but were most numerous in May, when the following species were seen: blunt-nosed, straw-colored, black-chinned and Cayuga minnows and golden shiner. On May 21 the Cayuga minnow appeared to be spawning on the shoal. Other fish seen or taken here were the mud minnow (very common in the dense growth of plants near the shore) chub-sucker, yellow catfish, common bulhead, barred killifish, rock bass, perch, *Etheostoma iowæ*, and least darter. The young of several species of fish were very numerous here in early summer, among others, those of the perch and sunfish.

Of the invertebrates casually noted at this station the dragon-flies and damsel-flies were common, and numbers of their empty larval cases were attached to the bulrushes. A leaf-eating beetle, *Donacia*, was common about lily pads. The whirligig beetles were common in the summer. Sialis adults appeared in large numbers among the bulrushes late in May, and one was observed laying eggs on the stem of one of these plants on May 29; at this time and later, black, waxy, oblong masses of eggs of these insects were often seen on the bulrushes.

The shoal here was one of the few places where living snails were common, although empty shells were abundant on most shoals and on the shores of the lake. On May 16, numbers of small specimens of these mollusks were seen on filamentous algæ, and proved to represent four species, *Planorbis parvus*, *Amnicola limosa*, *Valvata tricarinata*, and a species of Pisidium. In April two species of leeches were collected at this station. Of vertebrates, large green frogs were usually seen or heard throughout the summer. Birds were common in the swamp, but were not studied. The red-wings were abundant, and lived and nested among the cattails, as did also the marsh wrens. Kingfishers were common at this station.

DEEP WATER TYPE.

As already stated, the types of stations thus far discussed generally include portions of the shore, and extend only to the lakeward boundary or deepest part of the pond-weed zone, which does not extend deeper than about 25 feet deep. Around much of the shore this depth is reached about

200 feet out, as shown by the 25 foot contour line on the map, Plate 14. In one region (station 46, at the eastern end of the lake), however, this line is some 700 feet from shore, while at the north end of station 24 (near the extreme north end of the lake) it is only about 50 feet from the shore. As indicated above, the average width of the belt of water shallower than 25 feet is probably between 200 and 300 feet, so that by far the larger part of the bottom is more than 25 feet from the surface. All stations within this area are called deep-water stations.

Observations seemed to show that the conditions in the entire deep-water area were similar, the chief differences being the depth of water, and as this undoubtedly affects fish life directly or indirectly, differences in depth were made the basis for classifying stations. The observations and collections made in this deeper part of the lake all point to the fact that microscopic algæ, chiefly diatoms, constituted almost the only plant life of deep water, the higher plants, when found at all, being of scant growth or restricted to small patches in the shallower places.

The bottom in deeper water appeared to have three distinct zones of quite different types of soil, according to the depth. Marl was the chief bottom soil over the shallow parts of the lake, and it extended only to a depth of about 39 feet. At depths of 40 to 50 feet, a loose textured brown mud covered the bottom, and was replaced at a slightly greater depth than this by a thick layer of fine-grained blackish mud which covered the bottom of the deepest part of the lake.

Station 200, the first deep-water station to be considered, was in that part of the bay at the west end of the lake, west of the marshy peninsula and of a line running straight south from it. It had an area where the water was from 30 to nearly 60 feet deep. The method used to discover the nature of the bottom at this station was to draw a hook-and-net drag across it in several directions. In May, while dredging with this along the eastern border of the station, a mass of water-moss caught on the hooks and was brought up to the surface, but, as it was not found again in several trials, it seems probable that it was drift material, or occurred over but a small area of the bottom. On July 20 three hauls more made over the east and central parts of this station, in water from 40 to 50 feet deep, but none of the larger plants were found, except a small fragment of hornwort, which is a generally rootless form, hence without significance.

In each case the net part of the drag was brought up filled with grayish-brown mud, the temperature of which, taken as soon as possible after reaching the surface, was 15° C. A few midge and *Corethra* larvæ were found in this mud.

As it was impossible, on account of the depth of the water, to make observations on the fish life at this station, except rarely when fish were seen near the surface, practically all the information gained concerning the fish life was through collections. One of the few direct observations was made on July 19, when a large school of perch-fry was seen near the surface, about 300 feet from shore, where the water was about 40 feet deep. These fish averaged about an inch and a half long. The following species of fish were taken by the fyke and gill nets at this station during the season: perch, common sucker, whitefish, and wall-eyed pike. The suckers and whitefish netted here had been feeding on midge larvæ and on the crustacean, *Daphnia*. A tabulated statement regarding the collections will be found on a subsequent page (251).

Station 225 was that area on the southwestern part of the lake, where the water was from 60 to 80 feet deep. It began just east of station 200 and completely surrounded station 250, which included that part of the bottom over 90 feet from the surface. The bottom material at station 225 was a fine-grained, compact deposit of black muck which was light in weight, and supported a considerable microscopic fauna and flora. The former included, during late summer, numerous midge larvæ and the latter, diatoms. (See descriptions of the bottom samples taken at station 200 above, which were more carefully studied than those from this station.) In July, while making collections of midge larvæ at this and other deep-water stations, an apparent relation was observed between the numbers of larvæ taken and the depth of water in which the collecting was done, in that the larvæ seemingly increased in numbers as the water became deeper, but much more work needs to be done to confirm this observation. However, it should be pointed out that if the deep water has more of these organisms than the shallow, there would be more food for fish in the deeper parts of the lake, and certain species would probably tend to congregate there. In April a few temperature readings were made at this station, by the use of a thermophone, which later got out of order and could not be used. The results are given below:

Date	April 16	April 17	April 18
Time of day	11:00 A. M.	4:40 P. M.	4:30 P. M.
Temperature C. at surface	7.	7.5	7.4
Temperature C. at 20 feet	5.4	5.6	5.2
Temperature C. at 40 feet	5.3	5.5	4.9
Temperature C. at 60 feet	5.3	5.3	4.8
Temperature C. at 80 feet (bottom)	5.	....	....

Fish taken here (by the use of the gill-net) were the whitefish and common sucker. Details of the food and other data relating to these fish will be found on pages 244–251.

Station 250 included the deepest part of the lake, where the water ranges from 90 to 101 feet deep. As shown by the contour map (Plate 14), it was located on the southwest side of the lake, from 500 to 1000 feet north of station 23. It was elliptical in shape, and about 200 feet wide and 700 feet long.

It is evident from the study of many samples that the soil of the bottom at this station was the same constitution over its entire area. It is dark gray, almost black in color, and is made up of very fine particles, so small and light that it takes more than an hour for them to settle to the bottom of a shallow dish. A microscopic examination showed black and light-brown inorganic particles, and the remains of organisms such as shells of diatoms and Entomostraca. Living diatoms, rotifers and other microscopic forms of plant and animal life were abundant, and midge larvæ, in cases made of soil particles, were present in great numbers, especially in late summer. *Sayomyia* larvæ were also common. (See the report on insects, Appendix III of this report).

The only fish caught at this station were whitefish which were taken by means of the gill net, and but few specimens of these were secured. The identifiable material in the alimentary canal consisted chiefly of midge larvæ.

The following table gives such temperature readings as were made here; the surface readings were made with a standardized thermometer, and those from deep water with the thermophone, except those made on August 25, in which maximum and minimum thermometers were used.

Depths, feet.	May 5	May 7	May 27	May 28	May 29	June 9	August 11	August 14	August 25
Surface				16.5	16.5		24.	25.5	25.6
2½									25.7
5									25.6
7½									25.4
10									25.3
12½									23.9
15									24.5
17½									22.
20								17.8	18.4
22½									16.
25									13.5
27½									10.4
30									10.4
32½									10.1
35									8.7
37½									8.8
40							7.5	8.1	8.2
45									7.2
50									6.8
55									6.4
60							6.5	6.4	6.4
65									6.6
70									6.6
80							6.5	6.4	6.4
90			6.						6.4
100	5.9	5.3		6.1	6.1	6.	6.5	6.4	6.4

On August 25 and 26 Dr. John Eastwood, with the assistance of Professor Jacob Reighard, determined the gas contents of the water at this station at different depths where the bottom was a hundred feet below the surface. The purpose and results of this work are given in the following report written by Professor Reighard:

"At a depth of nearly 30 meters, there are found living in the bottom ooze of Walnut Lake numerous larvæ of a species of midge or *Chironomus*, and in the water immediately overlying the bottom, is an abundance ot *Daphnia*. Whitefish were found to feed on both of these forms. Since in most lakes of this depth and area the oxygen is practically exhausted in the deeper waters during the summer, so that *Chironomus*, *Daphnia* and fish cannot live there, an effort was made to learn what the conditions at the bottom of Walnut Lake were which made it possible for these animals to thrive there in mid-summer.

"The methods used were those described by Whipple and Parker* and the results are given in the following table.

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*Whipple, George C., and Parker, Horatio N., 1901. On the amount of Oxygen and Carbonic Acid Dissolved in Natural Waters and the Effect of these Gases on the Occurrence of Microscopic Organisms. Transactions of the American Microscopical Society, Vol. XXII, pp. 103–144, pls. XIX–XXII.

Table showing the amount of dissolved oxygen and carbon dioxide at various depths in Walnut Lake, Oakland Co., Michigan, on August 26, 1906.

Depth in meters.	Temperature in degrees centigrade.	Carbon dioxide in parts per million.	Oxygen in cubic centimeters per liter.
0	25.8	—3.5	5.486128
1	26.4	—3.15	5.176206
2	25.6	—2.55	
3	25.3	—1.95	5.078379
4	25.2	—2.10	
5	23.6	—1.65	5.40917
6	19.	—2.4	5.6618
7	14.9	+0.5	5.1947
8	12.5	+1.	3.9202
9	10.3	+2.	3.886
10	9.1	+3.	3.1606
15	7.4	+7 +5	1.782
20	6.8	+6.5 +7 +7	1.0008 1.315*
25	6.4	+7. +8. +7.	1.4456 1.0324*
28	6.4	+7.5	.9823 .9545*
29	......	+6.5	.5809 .727*

"The results are also shown in graphic form in the diagram, Fig. 18. From these results it appears that the volume of oxygen present at the surface is that usual in lakes at this time of the year, as shown in Birge's (1907) chart† of Lake Mendota on August 31.

"To a depth of about five meters the oxygen diminishes somewhat and then increases until at six meters it is slightly greater than at the surface. In this respect the lake resembles Elkhart lake and Beasley lake, as described by Birge, except that the increase is much less than in those lakes. As pointed out by Birge this increase in oxygen is due in Beasley and Elkhart lakes to the presence at a distance of five or six meters below the surface, of algæ, which in their ordinary metabolic processes use up carbon dioxide and liberate oxygen. In this way the water at this depth comes to have in solution an amount of oxygen in excess of that in the more superficial layers, and the total volume of water capable of supporting animal life is thus materially increased. Below seven meters in Walnut Lake the volume of oxygen per liter of water rapidly diminishes. At a depth of twenty-eight meters it is still about one centimeter per liter, and at twenty-nine meters it is six or seven-tenths of a centimeter per liter. As a glance at the map shows (Pl. 14), a depth of twenty-nine meters occurs over a very small part of the lake bottom, so that we may safely say that over nearly the whole bottom in mid-summer there is present not less than one cubic centimeter of oxygen per liter of water, while at depths of fifteen meters or less there is two or more times that amount.

"If we compare this condition with that found by Birge in Wisconsin lakes, it appears that in Lake Mendota the oxygen is entirely exhausted at the end of August at a depth of about thirteen meters. This exhaustion is attributed by Birge to the decay of the abundant organic matter present in the form of plankton in the surface waters of the lake. As this plankton falls to the bottom in mid-summer and decays the oxygen is exhausted, since in the process of oxidation it enters into combination with the organic matter. The bottom waters of this lake are thus devoid of oxygen during the greater part of summer, and at the end of that season no fish or other higher animals can live in them. At other seasons these deeper waters contain oxygen. Lake Mendota is thus in sharp contrast to Walnut Lake whose waters contain oxygen at all depths even in mid-summer. Not only are the deeper waters of Lake Mendota unfit to support fish in summer by reason of their lack of oxygen, but they are unfit on account of the absence from them of sufficient animal life to serve as food for fish 'to support any considerable amount of fish life at any time of the year' (Birge).

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*The values given for oxygen were those obtained in the last of three series of observations except the starred values, which are the averages of all observations made.

All values obtained for Co^2 are given in the table.

†Birge, E. A., 1907. Gases Dissolved in the Waters of Wisconsin Lakes. Transactions of the American Fisheries Society, 1906, pp. 143–163, 12 figures.

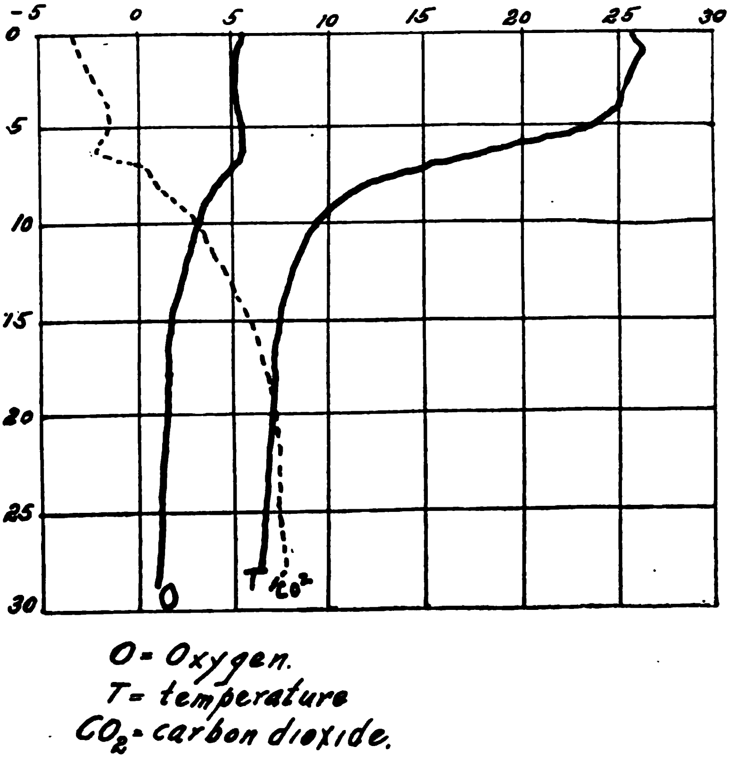

Fig. 18.—Diagram showing results of gas analyses of water at different depths at Station 250.

"In contrast to Lake Mendota is Trout Lake, Wisconsin, also investigated by Birge. At the bottom this lake contains about the same amount of oxygen as Walnut Lake, but between the bottom and the eight meter level it contains a good deal more. Above the eight meter level it contains about the same amount of oxygen as Walnut Lake. The lake was examined on September seventh. Birge reports that the true whitefish and the lake trout inhabit its deeper waters during the summer. It thus appears that these fish are able to live where the oxygen content of the water is not more than one cubic centimeter to the liter. This amount of oxygen is present in the bottom water of practically the whole of Walnut Lake during the summer. It is its presence there which enables the lake to support whitefish. Not only does the water at the bottom contain sufficient oxygen to support the whitefish, but what is quite as important it contains sufficient oxygen to support the food upon which the whitefish largely lives, the Chironomus larvæ and the Daphnia.

"No investigation has been made of the amount of organic matter or of plankton in the waters of Walnut Lake. It is to be presumed that Walnut lake, like Trout Lake, contains relatively little plankton. Of lakes otherwise alike that one which contains the greatest amount of plankton will contain the least oxygen in midsummer, while that one which contains the least plankton will contain the greatest amount of oxygen in midsummer. Lake Mendota belongs to the first of these classes, while Trout Lake, and presumably also Walnut Lake, belongs to the second class. In lakes of the first class the oxygen of the deeper waters becomes exhausted in summer by the decay of the abundant plankton and these waters are therefore unable to support animal life. In lakes of the second class the oxygen does not become exhausted by the decay of the plankton and the deeper waters are able to support fish and fish food throughout the year".

FISH OF WALNUT LAKE.

BY T. L. HANKINSON.

As the work of the party was concentrated on problems concerning the fish-life of the lake, efforts were made to obtain specimens of all of the species in the lake. Thirty-one species were taken, and, although other species are probably to be found, this collection may be taken as highly representative of the fish fauna of the lake. Among the species that we may have overlooked is the lake trout, several plantings of which have been made in the lake at various times, both by the Michigan Fish Commission and the United States Fish Commission. The following table will show the number and date of each planting.

Michigan Fish Commission	6000	in	1878.
" " "	3000	"	1879.
U. S. Fish Commission	1500	"	1889.
" " "	500	"	1892.
" " "	2700	"	1900.
" " "	7996	"	1901.

Those planted by the U. S. Commission were yearlings. In 1890 the Michigan Fish Commission examined Walnut Lake, and, with a gill net set in from 70 to 80 feet of water, caught 6 lake trout, the largest of which weighed one and one-half pounds. The planted fish thus appear to have lived, and there is little reason why the species should not be present in the lake now.

The fish fauna of Walnut Lake was found to be very different from that of the few others in its neighborhood which were examined. Two of these, Simpson Lake and Orchard Lake, will serve as examples. The first named is a small body of water less than a half-mile west of Walnut Lake, whose outlet joins that of the latter, thus forming a water-way between them. This lake abounds in calico bass, *Pomoxis sparoides*, but none were found in Walnut lake. In Orchard Lake 21 species of fish were taken at the single visit made on June 18, six of which were not collected at Walnut Lake. These six species are as follows:

1. Bow fin, *Amia calva* Linnæus. One found dead near shore.
2. Lake herring, *Argyrosomus artedi*, (Le Sueur). One found floating dead.
3. Rosy-faced minnow, *Notropis rubrifrons* (Cope). Abundant.
4. Brook silversides, *Labidesthes sicculus* (Cope). Abundant.
5. *Schilbeodes miurus* (Jordan). One taken.
6. Manitou darter, *Percina caprodes zebra* (Agassiz). One taken.

The remaining fifteen species taken on this day and also found in Walnut Lake are as follows:

Blunt-nosed minnow, Cayuga minnow, straw-colored minnow, common shiner, *Notropis anogenus*, barred killifish, blue-green sunfish, long-eared sunfish, blue-gill, common sunfish, black bass, perch, *Etheostoma iowæ*, Johnny darter and least darter. These observations show the value of detailed examinations of different lakes from the standpoint of fish environments, for the differences in fish faunas are possibly due to differences in the environmental conditions.

CONDITION OF FISH.

In a general way it may be said that fish thrive in Walnut Lake. The mortality of individual fish, due to natural causes, was apparently small, and relatively few dead fish were found, although in early spring, dead sunfish, chiefly blue-gills and blue-spotted sunfish (the latter more often), were occasionally found floating or cast ashore. In summer, perch were commonly found dead, while on the other hand, not more than six dead whitefish were seen during the entire season. All of the fish caught appeared in a normal or healthy condition, and some, notably the black bass, were conspicuously fat.

SPECIES, RELATIVE NUMBERS AND ECONOMIC IMPORTANCE OF THE FISH.

Of the total number of thirty-one species of fish collected in this lake, two-thirds, including practically all of the food fish in the list, may be considered common. These are given in the list below, as nearly as possible in the order of their apparent abundance: perch, blunt-nosed minnow, straw-colored minnow, blue-gill, common sucker, whitefish, common sunfish, large-mouthed black bass, pike, least darter, rock bass, wall-eyed pike, yellow catfish, common bullhead, golden shiner, black-chinned minnow, Johnny darter, blue-spotted sunfish, Cayuga minnow, *Etheostoma iowæ*, and barred killifish.

The species of fish that may be considered rare or uncommon are listed also in the order of their apparent abundance: chub sucker, tadpole stone-cat, *Lepomis euryorus*, common shiner, little pickerel, miller's thumb, brook stickleback, *Notropis anogenus*, and chub or horned dace.

It will be noted that more than a third of the forms known to occur in Walnut Lake are well-known food fish, some species being prized for their excellent flavor and high value as food, as well as for their gaminess when taken with rod and reel. These facts make the careful inquiry into their habits the more interesting and important, since it is fair to infer that these do not materially vary in other places where the same species are found.

METHODS OF FISHING.

Although good sized individuals of species most sought after for food and sport abound, yet Walnut Lake is reported to be a poor place for fishing with hook and line. The black bass, grass pike and wall-eyed pike, all excellent game fish, are common, but few are caught with the hook, judging from the reports of the people living in the neighborhood. Some attribute their failure in this sport to the great numbers of small fish and crayfish in the lake. It is possible that this abundance of natural food, combined with the facts that unattractive baits are used, and unfavorable fishing places are chosen, may account for the poor success reported. A most pernicious and unwise destruction of the larger fish is being carried on by methods of fishing contrary to the fish and game laws of the State. Illegal fishing, such as by gill net and spearing, was not uncommon, and jack-lights were often seen moving about on the lake on dark, still nights in the spring. In the spring fish were frequently caught by us with spear wounds thickly covered with water mold, and fish dead from the same cause were often found. Spearing is particularly disastrous to the more important fish, since the grass pike, black bass and whitefish resort to shallow water to breed, and not only the breeding adults are reduced in numbers by spearing, but the eggs and young are left unguarded and fall prey to numerous enemies against which, in the case of the bass at least, the old fish in part protect them.

The practice of spearing ought to be stopped, since the laws against it are based on sound biological principles, which must be observed if the fish are to maintain themselves in present numbers.

ANNOTATED LIST OF FISH IN WALNUT LAKE.

The following accounts of the habits and habitats of each of the thirty-one species of fish obtained is a summary of the field work of the party during the summer:

FAMILY *Salmonidæ.*

1. Common whitefish, *Coregonus clupeiformis* (Mitchill). This species is rated by many people the best of fresh-water food fishes. It was found apparently abundant in Walnut Lake, where it was possibly native, since Mr. Frank Crawford, a farmer living in its vicinity, reported that his father and Mr. Henry Grinnell caught these fish from the lake as early as 1840. Three plantings, aggregating over 100,000 artificially propagated individuals, were made by the Michigan Fish Commission as follows: 3,000 in 1874, 40,000 in 1878 and 60,000 in 1879.

Habitat.—At present the whitefish is an abundant resident of the deeper parts of the lake, where there are practically no plants except the microscopic one-celled algæ. It does not seem to visit the pond-weed zone to any extent, since but three of the 47 specimens taken were captured in that region, and those were found where the water was about 20 feet deep. A single specimen was taken in water about a foot in depth near the shore of station 3, on the night of April 18th. As pointed out below, all of these visits of the fish to the shoaler parts of the lake may be correlated with the movements of the organisms used for food.

Food and feeding habits.—One of the most important observations made relating to the whitefish was that of its almost exclusive use of midge larvæ for food during part of the year. The larvæ mentioned are small, reddish, worm-like insects from about one-half to two-thirds of an inch long, and are the young of the two-winged midges which closely resemble mosquitoes, and which in the spring appear in vast numbers about many lakes and ponds. The young, or larval stage, is passed in the mud at the bottom of the lake. In early spring the larvæ begin to change to pupæ, and from the last two weeks of April to early summer seek shallow water, and emerge as the adult, winged midges; these, after the eggs are laid in the water, soon disappear.

During early spring, and until June 2, when fishing in deep water with the gill net was suspended, the stomachs of 30 out of 38 specimens of whitefish taken or found dead were examined. These were all large fish, from 14 to 20 inches long, and weighing from 1½ to 2½ pounds each. Eleven had no identifiable food in the stomachs, and one had but a few mollusks shells. In the remaining 19, midge larvæ and pupæ were by far the most conspicuous and abundant material, constituting a large part, or in a number of cases the entire, food mass. Several of the fish in the last lot had 200 or more midge larvæ in their stomachs, and one speared near shore in a foot of water contained 200 pupæ. Larvæ of Sayomyia, Sialis, and other insects, mollusks shells, and in a few examples fish remains, constituted a small part of the food in each of these stomachs. It appears that at this season the whitefish are bottom feeders, since the midge larvæ are probably found only at the bottom, and appeared to be most abundant in the deeper parts of the lake. The pupæ seek the shoaler water, and, as the fish taken in the pond-weed zone and on shoals had been feeding on these, it is probable they were in shallower water seeking their favorite food.

In August, after two months' disuse, the gill net was set again in deep water for a few days, and 9 additional fish, weighing from 1¼ to 2¼ pounds were caught. An examination of these specimens showed that there had apparently been an entire change of food since early June, for these fish had eaten no midge larvæ, but had been feeding exclusively upon small entomostracans of the genus *Daphnia*. As the masses of this food found in the stomachs were clean and free from dirt of any sort it was inferred that the entomostracans had been taken from above the bottom.

Breeding habits.—The field season closed before the breeding time of the whitefish, but the farmers on the vicinity of the lake reported that the fish visit the shoals at the east end in large numbers in November, at which time they are caught by spearing. The visit to shallow water at this season is undoubtedly for the purpose of spawning, and the gravelly shoals of stations 46 and 49 presented conditions similar to those in which the species is known to spawn in other waters. The reproductive organs of most of the specimens studied were in a well-developed condition. No small fish were taken under a pound and a quarter in weight, which was probably due to the large size of the mesh of our gill net.

From the evidence obtained it seems very probable that the species does breed in Walnut Lake, and that those examples caught were probably not those planted by the Fish Commission from 25 to 30 years ago (see table of data given on another page.)

FAMILY *Cyprinidæ*.

THE MINNOWS.

Minnows of eight species were found (some in great numbers), and the species are named in the order of their apparent abundance: (1) blunt-nosed minnow, (2) straw-colored minnow, (3) golden shiner, (4) black-chinned minnow, (5) Cayuga minnow, (6) common shiner, (7) horned dace, (8) *Notropis anogenus*. These small fish were often found in great schools in shallow water, especially during the spring and early summer, but the pondweed zone seemed to be their permanent habitat. From this zone they migrated to the shoals in an irregular and seemingly erratic manner, being common on certain shoals on one day and scarce or absent the next, or even a few hours later on the same day.

The minnows were undoubtedly controlled in these movements by a number of factors of which the following seem most important: (a) food, (b) character of the bottom, (c) temperature of the water, (d) force and direction of the wind, (e) breeding impulses.

(a) Food.—This is apparently an important factor in directing movements to the shoals, as indicated by the numbers of minnows on the shoals bordering the marshes of the east shore (station 46), in the spring, when the midges were numerous there. An examination of stomachs at this time showed that midge larvæ and adults were then the chief food of these fish. After the latter part of May, when the midges became scarce, the fish also became much less common on these shoals. Minnows were also usually abundant about the nests of larger fish on the shoals, and were often seen eating the eggs and young, showing that they were probably attracted to the shallow water by the presence of this food.

(b) Character of the bottom material.—Minnows were more often seen on shoals with gravelly bottom, or those supporting a good growth of plants. This factor is undoubtedly closely related to (1), for such shoals certainly furnish more fish food than those with marl bottom, or those with scant vegetation.

(c) Temperature of the water.*—While variations in the temperature of the shallow water were marked, and an attempt was made to correlate them with the movements of the minnows, the data obtained were insufficient to establish any relationship, especially as this factor was very difficult to separate from the others. Certain observations, however, seem to indicate that minnows gathered on those shoals where the water was warmest, as shown by the following data:

Station 40, May 29.

Time.	Water temperature.	Minnows.
8:00 to 11:30 A. M.	18° C.	Scarce.
2:00 P. M.	21° C.	Abundant.

At station 3 on the same date the fish were seen moving towards the part of the shoal where the temperature was 19° C., from places where it was only

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*The observations on the effect of temperature and wind upon the movements of minnows were made by Mr. E. L. Michael, and most of the data given under this head are obtained from his notes.

17° C., and over a bottom which was of a similar nature throughout; it is doubtful if food conditions varied sufficiently to account for the movement of the fish at this time. On May 31st, from 7:30 to 9:30 in the morning, nine of the barren shoals with similar bottom conditions were visited, and the results given below were obtained.

Table showing relations of minnow movements to water temperature on barren shoals, on May 31.

Station.	Temperature of water, C.	Minnows.
3	16.°	Few.
11	16.°	None.
19	16.°	Very few.
23	15.5° —16°	Very few.
37	16.5°	Common.
45	16.5°	Common.
46	19.°	Very abundant.
32	19.°	Very abundant.

As shown by this table minnows were most common where the water was warmest. While making observations on the barren shoals, notes were also made on those covered with plants, and the data obtained are given for comparison.

Table showing the relation of minnow movements to the water temperature on plant-covered shoals, on May 31.

Station.	Temperature of water, C.	Minnows.
7	15.°	None.
31	16.°	None.
41	17.9°	None.
54	16.° —17.°	Abundant.
49	17.7°	Abundant.

At these stations conditions were much more varied than at those in the first set, and the food factor was doubtless more important in its influence. It is difficult to understand the absence of fish from station 41 at this time, but in the afternoon of the same day, when the temperature had risen to 25° C., minnows and other small fish were numerous here, and a large collection was made.

As a whole, our observations (extending from early April to June 1st) indicate that from early April to June 1 minnows were found most common on shoals where the water temperature was from 17 C. to 27 C. Furthermore the temperature of the water also seemed to affect the activity of the minnows for in the early spring, when the temperature of the water was only slightly above the freezing point, they were very sluggish.

(d) Force and direction of the wind.—These factors apparently affected the movements and distribution of minnows, but probably through their influence upon the temperature. It was commonly noticed that when a strong wind was blowing the water would become cooler along the windward, and warmer on the lee, shores of the lake, and that at the same time minnows were usually most numerous near the lee shores. On May 29 it was noticed that minnows were common in a particular part of station 7, which, it will be remembered, is a shallow bay, nearly circular in outline, and with its mouth opening to the east (see another page 187). At the time the observation was made the wind was blowing from the northeast, producing currents towards the south side of the bay, where minnows were collecting. They could be seen moving toward this area from all parts of the station, following the currents so clearly that bits of paper placed on the surface, moved in the same direction, and collected in the same place.

During the colder parts of the year, strong winds must destroy large numbers of minnows and other small fish which frequent the shallows, since they are unable to move freely at such times, and the waves caused by the winds dash them ashore. On April 8th the waves, driven by an easterly wind with a velocity of twelve miles an hour threw up a ridge of drift material in which were found on the next day many minnows, darters and small sunfish, some of which were still living when found. Such winds are of frequent occurrence during the fall and spring, and must cause much mortality among the shoal-frequenting fishes.

(e) Breeding impulses.—The minnows undoubtedly collect on certain shoals, or certain parts of them, for spawning purposes, but to what extent is not known, as there were but few chances to study the breeding habits of these fish. Nests of the blunt-nosed minnow were common in shallow water where the bottom was gravelly, which may be taken as evidence that the breeding impulses must cause these minnows to come to shoals of this type.

Economic importance of minnows.—Our observations indicate that the minnows are used as food by the larger and more important fish to but a very slight extent;as very few of them were found in the stomachs of any species examined. They were often found in company with large black bass, sunfish and bullheads, but in all cases this association seemed a peaceable one, for the larger fish were never seen making attacks on the minnows, except to drive them away from their eggs or young. Fishermen also report that fishing with minnows as bait in Walnut Lake is not attended with success.

At least two species of minnows, the blunt-nosed and the straw-colored, do much damage by eating the eggs and young of other fish more important to man. All minnows feed on midge larvæ in spring, and these insects form the chief food of the whitefish, and an important part of the diet of other useful species, so that in so far as the minnows deplete the food supply of the larger fish they must be considered as an unfavorable factor in the environment of the food-fish.

(2) The blunt-nosed minnow, *Pimephales notatus* (Rafinesque).

Habitat.—This is the most common minnow in Walnut Lake, being found on shoals of all kinds, and also in the pond-weed zone. Its visits to the shoals were somewhat irregular, owing to the influence of the factors given above, but it was almost constantly present where the bottom was gravelly, and was more generally abundant where there were submerged plants than where the bottom was marly. During the summer it became much less common in shallow water than in spring, as did other minnows.

Food.—The food of this species varies very much, but consists chiefly of small organisms taken from the bottom, from water plants, and from the water. Individuals were frequently seen feeding on the eggs of black bass, Johnny darter, miller's thumb, and sunfish of three species. At station 23, on July 14, they were found eating newly-hatched fry of their own species. The contents of the alimentary canals of many specimens were examined during the spring, and from those studied it appears that midges, in various stages of development formed the chief food of this species, in April and May. Besides midges, filamentous algæ, desmids, entomostracans, and, in one case, beetles were found in the stomachs.

Breeding habits.—Many nests of this species were found between May 22 and July 14, but it is certain that this interval does not include the entire breeding season. The eggs were always found close together, attached to the flat, under surface of some object, usually a stone, but more rarely a piece of bark, a sunken board, or a fence rail. Each of these egg-clusters was guarded by a darkly pigmented male with pearl organs. The fish remained constantly in the hole beneath the eggs until they were hatched, but apparently did not attend the young after hatching.

A nest, with the attendant male, was placed in an aquarium at our head quarters; the fish immediately went under the stone, stood guard as usual, and remained even after the minute young had hatched and swam away. A similar case was noted in the lake, where the male fish remained guarding the empty nest for more than a day after the eggs had all been hatched. Plate 58 shows a piece of bark found at station 35 on June 24, with eggs of the blunt-nosed minnow attached, Plate 56 a nesting place of the blunt-nosed minnow on the gravelly shoal of station 23 (a nest was under the stone marked "y" when the photograph was made on May 20). Plate 57 is another view of a part of the bottom at station 23, where, on June 27, there was a nest under the largest stone shown in the picture.

(3) The chub or horned dace, *Semotilus atromaculatus* (Mitchill).

The chub was very common in the outlet, but only a single specimen was taken in the lake, station 9. A few were caught near the lake, in one of the small inlets in the swamp zone of station 40. The species bred in the outlet, and a number of nests and spawning fish were found there on June 1st.

(4) The golden shiner, *Brama chrysoleucas* (Mitchill).

This species differs from the other minnows of the lake in having a flat body, so that seen from above it appears long and slender. The largest individual seen did not exceed five inches in length.

Habitat.—It was common in all places where there were many water plants, but its favorite haunts were stations 40, 54, 41, 7, 26 and 31. It was also taken on the shoals of stations 46 and 49 in the spring, at the time when other species were abundant there.

Food.—The stomachs of several specimens taken at station 46 on April 26 and May 21, were examined, and midge larvæ and filamentous green algæ were the chief food-materials found. Seven examined between July 8 and August 11 had been eating filamentous algæ, with which the intestines were distended.

(5) Cayuga minnow, *Notropis cayuga* Meek.

Habitat.—The favorite haunts of this fish were the plant-covered shoals of stations 40, 54, 41 and 7, where it was abundant. In early spring a few specimens were taken on the barren shoals of stations 16, 46, and 49.

Food.—The stomach contents of the specimens examined in April and May were chiefly midge larvæ, entomostracans and filamentous algæ.

Breeding notes.—On May 2, at station 40, a large, gravid female of this species was seen several inches above the sand, in company with many smaller ones, possibly males. She was apparently in the act of spawning, although no eggs were seen falling. The water at this place was about a foot deep, and the bottom hard and sandy, and covered with algæ.

(6) *Notropis anogenus* Forbes.

This species was apparently rare, as only two specimens were caught in the lake (at station 41 on May 31); a third was taken at Orchard Lake on June 18. The species closely resembles the black-chinned minnow in form and coloration, and has the same black margin to the lower jaw, but its mouth is very much smaller. The identification of the specimens was confirmed by Mr. R. E. Richardson.

(7) The black-chinned minnow *Notropis heterodon* (Cope).

Habitat.—The distribution of this form was similar to that of the Cayuga minnow. It was usually quite common at stations where vegetation was abundant, as at 40, 54, 41, and 7, and was also found at the east end of the lake, in the spring, when the midges were abundant on the shoals. On the night of June 21, at station 23, it was seen swimming near the surface over the pond-weed zone, apparently attracted by the searchlight used in making observations.

Food.—Specimens taken from the shoals in the spring had been feeding largely on the adult midges, the rest of the stomach contents being made up of filamentous algæ and a few entomostracans. On July 16th, three out of four specimens taken at station 7 had only filamentous algæ in the digestive canal, and the fourth a few insects.

Breeding habits.—The only records obtained on the breeding habits of this species was the capture of three gravid females at station 54 on June 16th.

(8) The straw-colored minnow, *Notropis blennius* (Girard).

Habitat.—This and the blunt-nosed minnow were the most widely distributed minnows in Walnut Lake. Both were common on the shoals, where they schooled together, but the straw-colored minnow seemed to inhabit deep water to some extent, as shown by the following records: On April 8th a specimen was dredged (with the triangle dredge) from the bottom in water from 20 to 30 feet deep. On August 13, about 25, small very light-colored specimens measuring from ¾ to 1¼ inches in length were taken from a large school of this species from near the surface in the middle of the lake. At station 3A this species was often seen with other minnows in deep water off the pond-lily zone.

Food.—The alimentary canal of the specimens taken in the shoals at the east side of the lake, in spring contained principally midges in various stages of development, with some entomostracans and filamentous green algæ. This species was often seen eating the eggs of other fish, and on May 24 a sunfish egg was found in the intestine of a specimen taken in a sunfish nest.

Breeding habits.—Nothing definite was learned of the breeding habits of this species. Of 30 specimens taken on June 25, from the deepest water of station 31, 8 were males with pearl organs in the form of minute granules over the head and body.

(9) Common shiner, *Notropis cornutus* (Mitchill).

Habitat.—This species was found to be common only in the south bay, chiefly at station 31 and occasionally at station 45. During the summer large individuals were often seen in these habitats, swimming either within a few feet of the surface or in water from 10 to 15 feet deep.

Breeding habits.—Shiners were abundant in the outlet of the lake, where they were seen spawning in June.

FAMILY *Catostomidæ*.

THE SUCKERS.

(10) The common sucker, *Catostomus commersonii* (Lacepede).

The individuals of this species taken were very uniform as to size and color, having an average weight of about 2½ pounds. Their backs were almost black, sides brassy, gradually changing to white below, and the lower fins were reddish brown in all the specimens studied.

Habitat.—Judging from the numbers taken in the gill net, this fish was very abundant, and seemed to be an inhabitant of water of from 15 to 40 feet in depth, although in April and May several were obtained at station 225 in about 80 feet of water. Owing to the fact that they lived in such deep water, no direct observations were made on their habits, but a farmer who spears fish through the ice in winter made the statement that in winter immense schools of suckers, roving close to the bottom in such numbers as to "make it look black," were often seen through spear holes in the ice. This fish was common in the outlet, where large specimens were sometimes seen at night (with the searchlight) near the lake (station 1). A few were again noted in this habitat on the night of April 10th, and on a single night in the middle of April a dozen or more large specimens were speared in the outlet Some days later the gill net was set in about 20 feet of water in the pond-weed zone of station 3, in such a way as to intercept fish going from deep water to the outlet, and when raised two days later about 50 large suckers, averaging 2½ pounds in weight, were found. This was the largest catch of this species made.

Breeding habits.—The abundance of individuals in the pond-weed zone, just mentioned, may have been due to the fact that they were on their way to the outlet to lay their eggs at this time. The outlet is undoubtedly a spawning place for those individuals which live in the lake, and April is apparently the month when they resort to the stream in the largest numbers to breed. Ripe fish were caught in the lake as late as May 20th, but there was no evidence to indicate that the species spawned in the lake, except that individuals were often found in pairs in the gill net. No young were seen in the lake, although they were common in the outlet. Pearl organs were present on the rays of the anal fin, and those of the lower half of the caudal fin of many of the male fish taken in April and May.

Food and feeding habits.—The contents of the alimentary canals examined were as follows: Four, taken May 12th, had been eating caddice-worms with their cases, small bivalve mollusks, amphipods, some insects and marl. Nine specimens taken in August, at station 200 (in about 40 feet of water), had fed on nothing but midge larvæ, and the small entomostracan, *Daphnia*. In one of these fish *Daphnia*, only were found; in two, a mixture of *Daphnia* and midge larvæ; in the other seven, only midge larvæ. It is interesting to compare the food of the specimens taken in August with that of whitefish caught in the same haul of the net; the whitefish were feeding upon *Daphnia* only, apparently away from the bottom, while some of the suckers were feeding on midges at the bottom, and others on the *Daphnia* apparently above it.

(11) The chub-sucker, *Erimyzon sucetta oblongus* (Mitchill).

Habitat.—So far as observed, this fish was limited to places where the vegetation was abundant. It was noted at stations 7, 26, 40, 54, and 41. At station 7 they were seen occasionally in small openings among the bottom plants, into the protection of which they would dart when disturbed.

Because of their habitat, they were not easily caught, and but few were obtained.

Breeding habits.—A few small specimens, about ¾ of an inch long, were taken on June 16, at stations 26 and 40, and on May 3rd an adult male with four pearl organs on each side of its snout and many small ones on the anal fin was netted at station 40. Most of those seen were between 7 and 8 inches long. The larger fish of the lake feed on this species to some extent, for, on May 13, the caudal half of a large female containing many eggs was found in the stomach of a black bass.

FAMILY *Siluridæ*.

THE CATFISHES.

(12) The yellow catfish, *Ameiurus natalis*. (Le Sueur).

Description.—It is probable that this species is not distinguished from the common bullhead by most of the people fishing in the lake. While the two species are similar in form, the one under consideration has a broader head and a larger anal fin than the bullhead, and is distinctly yellowish-green in color, while the true bullhead is almost black.

Habitat.—The species was taken or seen at ten different stations, and seemed generally frequent in the pond-weed zone, from which it went into shallow water at night. Small individuals, under 4 inches in length, were common in shallow water where vegetation was dense, as at stations 7, 41 and 40.

Food.—The stomach contents of four specimens examined consisted of crayfish fragments, May-fly larvæ, midge larvæ and pupæ, and other insect remains.

(13) Common bullhead, *Ameiurus nebulosus*. (Le Sueur).

Habitat.—This fish was seen or taken at nine stations, with the yellow catfish, and in about the same abundance. The two species were undoubtedly closely associated in habitat and feeding habits.

Food.—Like the yellow catfish, this species is an omnivorous feeder, and in ten stomachs examined, crayfish, small fish, mollusks, entomostracans, leeches, beetles, and the larvæ of Hexagenia, Heptagenia, midges and dragon-flies were found.

Breeding habits.—One June 28, a school of small bullheads about a half-inch long, attended by two old ones 12 to 14 inches in length, was seen in water a few inches deep near the shore of station 4. At the approach of the observer the adults swam away, but returned to their charges several times in the course of two hours.

(14) The tadpole stone-cat, *Schilbeodes gyrinus*.

This is a small species of catfish, about 5 inches long, and was found in but two parts of the lake, stations 7 and 41 and the adjacent stations 3 and 37, where they were quite common in the dense vegetation of the shallow, almost stagnant water of the bays.

Food.—The stomach contents of a specimen caught at station 7, on May 23, consisted chiefly of a mass of insect fragments.

Breeding habits.—On June 26th, a fish of this species, 2⅜ inches long, with a cluster of eggs was found in an old tin can at station 35. The water at this place was three feet deep, and the bottom was marl. The eggs are shown in Plate 59.

FAMILY *Esocidæ.*

THE PIKES.

(15) The little pickerel, *Esox vermiculatus.* (Le Sueur).

A single specimen of this species was taken in the trammel net at station 36, on May 2.

(16) The pike or pickerel, *Esox lucius.* (L).

This is called the "grass pike" by fishermen of the region. In early spring, as soon as the ice disappears from the marshes, the pikes seek these habitats to lay their eggs, and are at this time much sought after by gunners. The species is very common, judging from the number of individuals seen in shallow water in the breeding season; at this time one or more would swim from every shoal approached, where there were bulrush stems or other plants remains, which afforded partial concealment. The largest number of specimens was taken in the trammel net at station 54, which seemed a favorite shallow water habitat.

The fish caught in the lake were mostly between 12 and 18 inches long; the largest was a little over 2 feet long and weighed 3½ pounds. A still larger fish was seen, which had been shot while spawning in a marsh near the edge of the lake, on April 2nd. It was a female, 28 inches long, with very large egg masses, and weighed 8¾ pounds.

Food.—Food was present in but nine of the many specimens examined. It consisted of a single perch in six cases; of two fish of the same species, about 3 inches long, in another, and 3 darters in another.

FAMILY *Umbridæ.*

MUD MINNOWS.

(17) The mud minnow, *Umbra limi.* (Kirtland).

Habitat.—This small fish was common only where the aquatic plants formed a dense growth in shallow water. It was never seen swimming in open water, all the specimens found being picked from masses of plant drawn from the bottom at stations 40, 41 and 7.

Food.—Of the four specimens examined for food, two were taken in April and two in July. The food was about the same in all of them, entomostracans, green algæ, water mites, midge larvæ, Planorbis shells and miscellaneous insect material being present.

FAMILY *Poeciliidæ.*

THE KILLIFISHES.

(18) The barred killifish, *Fundulus diaphanus.* (Le Sueur).

Habitat.—The killifish was seen at seven stations. It was most common along the east side of the lake, where, in the latter part of the spring, it was associated with minows.

Food.—Four specimens caught at station 41, on May 10, had fed on midge larvæ, water-fleas, and a small amount of filamentous green algæ. The stomach contents of specimens from station 46, taken on May 21st, was composed chiefly of midge larvæ, beetles, and water-fleas, and several that were caught on May 31st had been feeding on midge and May-fly larvæ. In general, it may be said that these fish seemed to take the same kinds of food as the minnows with which they were found associated.

FAMILY *Gasterosteidæ.*

THE STICKLEBACKS.

(19) The brook stickleback, *Eucalia inconstans* (Kirtland).

Habitat.—This species was only found in the stagnant, duck-weed covered pools in the swamp at station 42.

FAMILY *Centrachidæ.*

THE SUNFISHES.

(20) The rock bass, *Ambloplites rupestris* (Rafinesque).

Habitat.—The rock bass was a very common species at Walnut Lake. It was often seen in shallow water, but apparently the pond-weed zone was its principal habitat, and it visited the shoals in search of food and breeding grounds. It was abundant on the bulrush-covered shoal at station 54, and a number were caught in the fyke net collections made in the pond-weed regions of stations 15, 12, 3, 6 and 26.

Food.—The stomach contents of 19 individuals taken between April 19th and June 26 were examined, and the following animals found: Crayfish in 10; dragon-fly larvæ in 6; midge larvæ in 2; small fish in 1; May-fly larvæ in 1. Crayfish thus seemed to form the most important part of the food of this species in Walnut Lake.

Breeding habits.—Four nests of rock bass were found at station 24. They were all in water less than two feet deep, and on a marl bottom covered by a scant growth of bulrushes. The first nest was found on June 6th; it was about 20 feet from shore, in about a foot of water, and was guarded by a large adult. No arrangement of the bottom material to form a nest could be seen, but in the area guarded by the bass, among the small stoneworts which here, as elsewhere on the shoal, formed a dense growth, were some very young fish about ¼ inch long. The parent fish was not frightened when the water-glass was placed above it, and was so bold that it would bite a hand placed in the water near it. On two succeeding visits made within a few days, this fish was watching the young ones and showed the same boldness in their defense.

A second nest was found on June 12th, near the end of the same shoal, in water 17 inches deep. This was in a shallow depression of two or more inches. The depression did not, however, differ from the rest of the bottom (which was of marl and covered by small stoneworts), and showed no signs of recent disturbance. The attending fish was about 10 inches long, and had no fear of the observer, being even bolder than the first described; it seemed very successful in keeping away minnows. The young were not found on the next visit, but their presence was apparent by the actions of the fish, and the empty gelatinous egg-cases fastened to the stoneworts. Two days later a young fish ⅜ of an inch long were found among the plants in the bottom of the nest. The fish was still guarding this nest on June 16th. On the latter date, a similar nest was found on another part of the same shoal, in 17 inches of water. Many eggs were found attached to stoneworts in this nest.

(21) The blue-spotted sunfish, *Lepomis cyanellus* Rafinesque.

Habitat.—But little information was obtained concerning the distribution of this species. Few specimens were taken, and these were caught in a trammel net, chiefly from shoals where plants were abundant. They were seen more often than caught, and are recorded from stations 26, 7, 41, 31, 15, 19 and 20, but none were ever taken from the pond-weed zone by the drag seine or fyke net. In early spring individuals of this species were often found dead in the water.

Food.—Of eleven stomachs examined, crayfish were found in seven and dragon-flies in three; other organisms found, but which were apparently of minor importance, were leeches, small fish (including a small sunfish), water-mites, and miscellaneous insect remains. The crayfish seems to be the most common food of this species.

Breeding habits.—The first nest of this sunfish was found early in July. It was in water nearly a foot deep, and near the shore of the east end of the swamp loosestrife zone of station 26. It consisted of a depression about a foot wide and three inches deep in the black mud of the bottom, and was situated close to a sedge clump. In the depression there were many sedge roots, to which numerous eggs were attached (Plate 60).

Above the nest was a large, dark-colored male, with a coloration so similar to that of the bottom that its almost motionless body could scarcely be seen; it was further concealed by the light-colored border of its dorsal fin, which appeared like a blade of grass in the water. A small female was seen to deposit eggs in this nest July 3rd, and when revisited on July 7th there were still a few unhatched eggs in it. It was vacated before the 13th, for on that date neither eggs, young, or attending fish were found; at that time, however, two other nests similar to it were found within a few feet, each attended by a fish of the same size and coloration as the first, and in one of these new nests there were minute young about 1-5 inch in length.

During July a number of nests of this species were found at station 4, which had the same general form as those described, but the eggs were attached to the roots of bulrushes. At this point the bottom was of marl, and the fish guarding the nests were, in all cases, much lighter in color than those at station 26, thus harmonizing with the light color of the marl bottom; the fins had the same light markings as those of the fish at station 26. This species, in Walnut Lake, resembles the common and long-eared sunfish and rock bass in its habit of choosing shallows for nesting, but makes a deeper and more conspicuous nest. The attending fish was also found to be less restless than those of the other species, remaining apparently motionless over its nest, from which, however, it is much more easily frightened than are the other sunfish studied. When disturbed, it darts away into deep water, and seldom returns to its post until the object of its fear is gone.

(22) *Lepomis euryorus* (McKay).

Habitat.—This is apparently a rare species in Walunt Lake, since it was found only at stations 31, 54 and possibly 4, while but one was taken in the first mentioned habitat, and only a few at 54. All of these specimens were caught in May. The single individual taken at station 31 was kept in an aquarium until June 16, and photographed while alive (Plate 61). It was 6¼ inches long, which was about the average length of those taken. The determination of this species was made by R. E. Richardson.

Breeding habits.—On June 28 a sunfish nest was found in the bulrush zone of station 4, in 15 inches of water. It was watched by an individual which, although not carefully examined, was probably of this species. It was so fearless as to allow itself to be taken from the water for a moment, and a chance was thus afforded to see that it differed in a marked degree from the long-eared sunfish, which it resembled in its coloration. The nest was a nearly circular depression three inches deep, in the marly soil of the bottom. The gelatinous egg-capsules were attached to the roots of the bulrushes, at the bottom of the nest, where there were also newly-hatched young. The parent fish was protecting the nest from numerous blunt-nosed minnows and several small sunfish, which were waiting to attack the contents. In the ten minutes or so which it took the owner of the nest to recover from the fright of being taken from the water and to return to the nest, one of the little long-eared sunfish from the attacking party rushed into the nest and began to drive out the minnows and sunfish. This small sunfish and some of the minnows were caught, and one of the latter contained four young fish like those of the nest.

The large fish was left on the nest, because it was so tame it was thought best to study its habits and photograph it, but on returning later it was gone, and was not seen again, hence was not positively identified.

(23) The long-eared sunfish, *Lepomis megalotis* (Rafinesque).

Description.—This species is very much like the common sunfish in general form and coloration, but differs from it in having shorter dorsal spines, a more rounded snout, and, in many adults, long, conspicuous opercular flaps or "ears." It was by no means as numerous in Walnut Lake as was the common sunfish, with which it appeared to associate.

Food.—Three specimens, the only ones taken in spring, caught at station 54, on May 9, had all been eating May-fly larvæ, dragon-fly larvæ, caddice-worms and leeches.

Breeding habits.—The species was more conspicuous in summer than in spring, and, after June 15th, nests were found at stations 4 and 54. In the former habitat two typical nests were found on July 1st near substation 4a, in the bulrush patch shown in Plate 62, and close to the outlet of the lake. The water at this place was 14 inches deep. The nests were shallow, nearly circular depressions, exposing the bulrush roots, to which the eggs were attached. Highly colored fish with long, conspicuous, opercular flaps were tending these nests (Plates 63 and 64.)

(24) The blue-gill, *Lepomis pallidus* (Mitchill).

Habitat.—The blue-gill was by far the most abundant species of sunfish in the lake. Its principal habitat was the pond-weed zone, in which it was common throughout the field season. It also frequented the shoals, especially those of stations 7, 15, and 54, on which, in the spring, many specimens were captured in the trammel net.

Food.—The stomachs of 18 specimens of this species were examined and, until the middle of May, caddice worms, crayfish, midge larvæ and pupæ, and the larvæ of *Heptagenia*, *Hexagenia* and *Sialis*, constituted the bulk of the food, the midges predominating. After that time, crayfish, grasshoppers, crickets, beetles and other land insects, together with entomostracans were the chief articles of diet.

Breeding notes.—The breeding season of the blue-gill was long. The first nests were found on June 4th, the first eggs on June 6th, while young only one-fifth of an inch long were found at station 12 on July 7th. The species is gregarious in its nesting habits, and many groups of from 9 to 15 nests were found on the barren shoals at stations 16, 3, 19, 23, 32, and 12, which were the chief breeding haunts. Groups of nests were also noted on the bulrush-covered shoals of stations 15 and 24.

The nests were always found in water from five to six inches to two feet in depth, and every nest was tended by a very shy fish, which was so timid that it was difficult to get near enough to see it at its station. All of the nests were of the usual sunfish type, i. e., circular depressions in the bottom soil. They were about two feet in diameter, from which the material had been cleaned away to expose the bulrush roots, to which the eggs were attached.

(25) The common sunfish, *Eupomotis gibbosus* (Linnæus).

Habitat.—This was the second sunfish in point of numbers in Walnut Lake. It seemed to have a greater preference for shallow water than the blue-gill, especially in spring, when they were very common on plant-covered shoals. In the summer, they were seldom seen in such places, except where the bottom vegetation was abundant, as at stations 7 and 41, where small individuals, about three inches long, were usually common.

Food.—The stomachs of 32 specimens of this species, taken between April 13th, and August 11th, were examined, and, while May-fly larvæ of the genera *Hexagenia* and *Heptagenia* seemed to be the favorite food, crayfish, amphipod crustaceans, snails, leeches, midge larvæ, caddice-worms, and other insects were all found in the contents. The midge larvæ were apparently eaten only in small quantities.

Breeding habits.—Like the blue-gill, the sunfish was found to be somewhat social in its nesting, but the nests were not placed so close together, nor in such deep water (usually between one and two feet only). The breeding season extended from May 21st, when the first nests were found at station 40, at least until July 7th, when two females were seen spawning at station 20.

The nests were shallow, circular depressions in the shoals, extending down to the bulrush roots. The eggs were attached to the bulrush roots, generally to one side of the center of the nest. Each nest was guarded by an adult male, some of which were very shy, while others paid little heed when observations were being made near them. Some of the adults were even very fierce in attacking intruders, while others would calmly watch the minnows help themselves to the contents of the nests. A list of the stations where this sunfish nested is given below, with notes on the character of the environment, and the date on which the first nest was found at each place.

May 21, station 40, on sand bottom.
June 3, station 26, on sand bottom.
June 14, station 24, on marl bottom, with scant bulrush growth.
June 24, station 4, on marl bottom; few bulrushes about the nest.
July 7, station 20, on marl bottom, bulrush-covered.

(26) The large-mouthed black bass, *Micropterus salmoides* (Lacepede).

Habitat.—This fish was a very common species, dwelling chiefly in the pond-weed zone, but, in the spring, frequenting the shallow water with the sunfish. In May and June it was almost constantly present in the shallow cove, station 7, and, during the same months, it was frequently seen in the bulrush zone of station 15. It was also a common occurrence on warm days to see a number of individuals swimming close to the surface of deep water over the pond-weed zone.

At station 54, in the spring, specimens, seven or eight inches or more in length, were common, and were often caught in the trammel net. The largest specimen taken was 17 inches long, and weighed 4¼ pounds. Besides these larger fish, extensive schools of bass fry, an inch or so long, were occasionally seen in June, and in August small bass 3 or 4 inches long were common on plant-covered shoals, such as those at stations 7 and 54. The numbers and uniform size of these fish indicate that they were hatched during the season.

Artificial introduction.—Black bass have frequently been placed in Walnut

Lake by the Michigan Fish Commission. The latest introduction was in the spring of 1906, when several thousands, obtained from the Fish Commission, were planted.

Food.—Data on the food habits were gathered from the examination of the stomachs of 24 fish caught between April 11th and June 10th. Nearly all of those examined had been feeding on crayfish, five had eaten one or more small fish, and one, taken April 28th, had in its stomach about 350 midge larvæ and pupæ, besides *Sialis* and damsel-fly larvæ. From these facts, it appears that crayfish are the most important food of this species in Walnut Lake.

Breeding habits.—Nests were found at stations 19, 20, 7, 40 and 54, but most frequently at 54. They were placed on shoals, in from one to two and one-half feet of water. The first nest was found on May 16, in the midst of a tract of water-milfoil plants, and in about 15 inches of water. It consisted of a circular mass of blackened roots from which the soil had been removed, and upon these were fastened great numbers of light-colored, small but conspicuous eggs. Other nests, having about the same appearance, were found later among the bulrushes, with eggs attached to the cleaned roots of these plants.

The nests were guarded by one, or sometimes two, fish. In some instances the guarding fish was quite fearless, and could be approached near enough to be studied carefully. Minnows were numerous in the vicinity of most of the nests, and, if the guardians were driven away, would rush in and eat the eggs. The nests were often deprived of their guardians by fishermen, who speared them at night, and such nests were soon stripped of their contents by minnows.

Economic.—This is one of the best and gamiest of the fresh-water food-fishes, and from its size and abundance in Walnut Lake should yield excellent sport, as well as quantities of good food. It is hardly necessary to say that it should not be speared from the nests.

FAMILY *Percidæ.*

THE PERCHES.

(27) The wall-eyed pike, *Stizostedion vitreum* (Mitchill).

This species was reported to be common in Walnut lake, but only ten were taken. These measured from 15 to 25 inches in length, and weighed from one to five pounds each.

Habitat.—Nine of the specimens obtained came from the pond-weed zones of stations 15, 6, 46 and 7, and the other one from the deep water of station 200.

Food.—The stomachs of all these specimens were examined, but were empty, except two. Of the latter, one from station 15 contained a perch 8 inches long, and the other from station 200, caught on August 6th, contained five small fish, each about an inch long, which seemed to be small straw-colored minnows, then very numerous near the surface of deep water.

Breeding notes.—A ripe male was caught on April 26th from the pond-weed region of station 6, and two females with large and numerous ova were found in the gill net on the same day, so it is probable that this date is included in the breeding season of the species in Walnut Lake.

(28) The yellow perch, *Perca flavescens* (Mitchill).

Habitat.—This is apparently the most abundant fish of Walnut Lake. It chiefly inhabited the zone of pond-weeds, but was commonly seen on the shoals in two or three feet of water, either singly, or, as was often the case, in large schools. Like the sunfish and bass, it was more often seen in shallow water in the spring than in the summer, during the day, but was seldom (except in the case of very young fry in the summer) found in less than two feet of water. With the aid of a searchlight it was found to be an abundant visitor to the shoals at night, when large numbers of scattered individuals could be seen resting quietly on the bottom at various depths, during both spring and summer. The fyke net, set in the pond-weed zones of stations 3 and 15, often caught from one to several hundred specimens after being down about a day.

Food.—Only thirty-two stomachs of the many which were examined contained food; of these 13 had numbers of midges in several stages of development, and 11 had crayfish. Other food material, in relatively small quantities, was found to include May-fly larvæ and a variety of other insects, besides snails, leeches and entomostracans. The few fry opened contained chiefly entomostracans, among which were copepods and ostracods.

Breeding season.—Perch were found breeding during the latter part of April. On April 23rd in the pond-weed zone of station 15, about 400 specimens were taken in the fyke net. Most of these were mature males, but there were four females, three of which were spent, while the fourth had eggs protruding from the body. Gelatinous masses of eggs were also found in the net. These females were much larger than the males taken with them. Schools of very young perch, sometimes containing several hundred individuals, were very common in June and early July, especially on shoals with much submerged vegetation, such as those at stations 7, 40, 26, 54 and 31. They were also observed in bulrush zones, and, less often, near the surface in deep water, several hundred feet from shore, in some cases as far out as station 200.

Economic importance.—The perch is one of the best of the smaller fish, ranking high as a pan fish, and if properly taken (with a light tackle) furnishes considerable sport. Its numbers and hardiness make it a valuable species in such lakes as the one under consideration.

(29) The Johnny darter, *Boleosoma nigrum* (Rafinesque.)

Habitat.—This very interesting little fish was a common inhabitant of the shallow water, ranging to depths of six or seven feet; beyond the latter depth it could not be detected with the water-glass. While noted on barren and bulrush-covered shoals, and on those with much submerged vegetation, such as stations 41 and 54, the barren shoals with gravel bottoms seemed to be the chief habitat.

Food.—The few specimens obtained in late April had been feeding on midge larvæ alone, or on filamentous green algæ, the same food which minnows, taken at the same time and in the same place, had been eating. A specimen caught on May 21st had been feeding on midge larvæ and entomostracans, but several taken on the next day contained only midge larvæ.

Breeding habits.—The eggs of this species were only found on the under side of small objects lying on the bottom in shallow water. The many nests found were under flat stones about the size of a person's hand, or smaller, a single exception was one that was placed beneath the valve of a mussel shell which lay concave side down.

The favorite breeding places were the gravel-covered, marly shoals of stations 23, 49 and 45, and nearly all of the nests noted between May 16 and June 19 occurred in these places. These nests were each guarded by a black-pigmented male, which was tireless in his attempts to drive away the numerous blunt-nosed and straw-colored minnows which were trying to get at the eggs, but his small size prevented the darter from injuring the intruders, and they gave him little attention. Doubtless the eggs were more protected by being covered than by the energy of their guardian.

(30) *Etheostoma iowæ* Jordan and Meek.

The habitat of this species appeared to be similar to that of the Johnny darter, but it was much less abundant. It was especially common in the shallow parts of the shoals of stations 6 and 16. At the latter place just after the ice had left (early in April), numbers of them could be seen swimming out into the lake, from beneath the sedge roots which fringed the shores. After the first of July it was not found on the shoals.

(31) Least darter, *Microperca punctulata* Putman.

This is the smallest species of fish found in the lake. Its maximum length is given as 1½ inches, but none were found in Walnut Lake that exceeded 1¼ inches.

Habitat.—In the spring the species was found on shoals having much aquatic vegetation, as at stations 7, 26 and 41. They were also common in the spring on the bulrush-covered shoals of stations 1, 15 and 4, but were scarce at all times on barren shoals, a few only being taken at station 49, late in May. Like most other species, the least darter practically disappeared from the shoals in summer. Some were caught, on July 9th, in the pondweed zone off station 6, in water from 15 to 20 feet deep, and it is possible that the fish seeks this area in summer.

Breeding habits.—Nothing definite was learned of the time of spawning or other breeding habits of this species. During May, pairs were often seen with the individuals united in what may have been the spawning position, the female resting near or on the bottom, and the male above. No eggs were seen, but this may have been due to their minute size. Males were also seen chasing females at this time.

FAMILY *Cottidæ.*

(32) The miller's thumb, *Cottus ictalops* (Rafinesque).

Habitat.—This fish was very common in the outlet, but only two specimens were caught in the lake. Both of these were seen on gravelly shoals, one at station 49, and the other at station 13.

Breeding notes.—The specimen noted at station 13 had a nest beneath a small stone on an area of stony bottom such as was used by the blunt-nosed minnows, for nesting purposes. The eggs were fastened to the under side of the stone, which is indicated in Plate 56 by the mark x.

THE FLORA.

BY C. A. DAVIS.

In an investigation of the character of the one upon which this report is based, it is impracticable to cover thoroughly all phases of the biology of any considerable part of the region around the spot where the intensive studies center, or to divert attention too strongly from the main problem under consideration. Therefore, while the plant relations of the broader field furnish a theme of great interest, but little space can be devoted to it here, and, so far as plants are concerned, attention will be directed chiefly to the flora of the lake and its immediate surroundings, since the fish, the central objects of this investigation, are directly affected by this.

Relations of plants to animals.—Plants are the organisms which stand between the highly specialized and complicated animal world and the inorganic or mineral kingdom, converting the gases and mineral matter of the latter into substances which can be assimilated by the former. Plants, then, may be termed the primary food of animals, even when these, as is the case with many fish, do not use them directly for food, for, if the history is traced back far enough, it will be found that there is one or more vegetable feeding organisms constituting the intermediate step from the mineral world to the animal.

Aside from this relation, plants furnish places of nesting, of refuge, and of rest for fish, and a study of the Walnut Lake records shows that the abundance of many fish and their permanence at any station was largely correlated with good plant growth.

Requirements of plants.—Before taking up in detail the flora of the lake, however, a brief statement of principles governing the distribution of plants over even the most limited areas, may not be out of place.

All green plants require for their growth and development, light, heat, water, the gases, oxygen and carbon dioxid, which they get from the air, and soluble mineral salts, obtained primarily from the soil, with the water taken in by the roots.

Adaptation of plants.—The absolute amount of these required by each species may differ, as may also their powers of resistance to unfavorable deprivation or excesses of some of them, hence we find plants growing in almost every kind of habitat, where all of these essentials are found, and presenting peculiarities of structure or form, which seem to fit them for the particular environment in which they occur. It is said of such plants that they are "adapted" to the conditions under which they grow.

Thus we find plants which grow in very dry places provided with extensive, wide-spreading root systems, with relatively small leaves protected from loss of water by a thick epidermis, covered densely by hairs, scales, wax or other forms of covering, or, as in some desert plants, the leaves themselves may be wanting. In like manner, plants growing in shaded places often have large, broad, thin leaves, and, to increase the light-absorbing surfaces, green bark on their branches.

Law governing plant distribution.—Since the requirements of the factors essential for plant growth are absolute, and if one only of these falls below the minimum amount needed by a plant to maintain itself, it perishes, it follows that plants unable to find all of the conditions necessary for existence in their environment must give place to those which can. This statement may be illustrated by the commonly observed fact that, if the water supply in the soil of a field decreases below a certain amount, crop plants cease to grow, and, if the unfavorable conditions continue, the plants die. All other conditions may remain favorable, but the failure of this one is effective in destroying the plants. On the other hand, at the time when one set of plants may perish, another set, because of a lower limit of tolerance, may not be injured at all, but may even flourish, a state of affairs sometimes seen during drought on cultivated lands, when weeds cover the ground, though the crops are dried up. Again, the presence of an excess of water in the soil may drive from it the air necessary to keep the roots of most land plants alive, and thus many species which might find all other conditions favorable are kept from very wet habitats, so that in marshes, where the soil is saturated with water, there are relatively few species of plants. It must also be apparent that if a single unfavorable condition for growth reduces the number of species, two such conditions will reduce the number still more, so that there are a great many less plants which will live with their leaves and roots submerged than if the roots only are below the water.

The flora of a lake and its immediate surroundings, therefore, must differ to a marked degree from that of the highlands in its vicinity, not only in species, but in the number of species, which will be much fewer than occur on the uplands, in the kinds of adaptations to conditions of growth, and in other ways, but especially in the number and simplicity of associations found. Above the water level of a lake, on those shores where the soil is simply wet, there will usually be more kinds of plants than are found growing in the water, because there are fewer necessary factors of growth affected, and until a certain optimum condition for rooted plants is reached, for practically every inch which the land surface is raised above the water level, there is an increase in the number of plant species which will grow on it and in the complexity of the associations into which these group themselves,

Types of water plants and their associations.—Where the soil is covered by water, within the margin of the lake itself, as has already been suggested, more than one factor of growth is different, and unfavorably so, from that of the normal environment of land plants, and we have fewer seed-plants and simpler associations. In the aquatic environment, some of the more highly organized plants grow entirely submerged, some send their leaves to the surface where they spread out, and still others have parts of their vegetative bodies entirely above the water, thus avoiding some of the difficulties of submergence.

Factors controlling plant distribution in a given lake.—The distribution of these types of species must be limited to those parts of a lake where they find favorable places for the growth of their underground parts (roots and stems), and to those from which, after they are established, they can grow upward to a place where sufficient light and heat reach their leaves to enable these to carry on their work of carbon assimilation. Most plants living in water, or wet places, propagate extensively by underground stems, which radiate horizontally from the established part of the plant. They are thus able to take possession of the lake bottom over large areas, and to such depths as the species extending its range in this way is unable longer to get enough heat and light, or is forced to meet other unfavorable conditions.

The lake a desert.—Since but few species, and still fewer orders,of seed-plants can tolerate aquatic conditions, the flora of lakes is monotonous, and consists of great numbers of individuals of few types; in other words, the lake is like a desert in that it usually has a sparse flora of highly specialized plant forms, which differ radically in structure and form from the plants of the higher lands adjacent, and have slight relation to them.

Reasons for zonal arrangement of plants.—Water and marsh plants because of the lack of competition with other more aggressive forms, and because of their habit of spreading below ground in soil very favorable for this purpose, will usually arrange themselves about the shores of the lake in about the order in which they can endure submergence, so that, if the slope is uniform and gentle, and the soil all of the same nature, the plants will form a series of rings or zones, of greater or less width, according to the steepness of the slope of the bottom, being wide if the slope is gentle, and narrow if it is steep.

Invariable order of the zones.—Each one of such zones will be characterized by the dominance of some plant or group of plants, so that it is easily differentiated from others and may be given a distinctive name, and while species may vary, and any zone may be wholly or in part wanting from a given lake, their vertical order of occurrence is invariable when they are present.

Limits of the different zones.—Beginning in the deepest water, the larger and more highly organized plants are absent, if the depth is more than twenty-five or (very rarely) thirty feet deep. Microscopic algæ are found at the bottom in water more than thirty feet deep, and the stoneworts, closely related to the algæ, frequently occur at depths of thirty feet or more, if the water is very clear. Seed plants of the submerged types, especially the pond-weeds, begin to appear sparsely in water about twenty-five feet deep, and are the only ones visible until the water is about 15 feet deep, when plants with floating leaves, like the water-lilies, begin to show themselves, and characterize a zone which extends shoreward until the water is about 5 feet deep. Then if the soil conditions are favorable, these monopolize the part of the lake where they grow, since the floating leaves crowd close together, and cut off the light from the water below, and prevent, or restrict, the growth of submerged plants. In water 5 feet deep, plants with aerial stems, like the bulrush and other grass-like plants, with some others, are able to establish themselves, and these may cover the marginal region to above the water level about the whole lake, providing other elements do not come in to interfere with the ideal conditions. The plants with aerial stems and leaves make a strong, dense growth where the composition of the bottom soil is favorable for this, and so cut off the light from the submerged types and from those with floating leaves, so that these either take a subordinate position or disappear from the association entirely.

Zones above the water level.—Above the water level, sedges in considerable variety, ferns, and many other types of herbaceous plants, displace the bulrushes and those forms which can grow in the water, and these in turn give way a short distance up the slope to the true grasses, which often form a distinct zone. At about the same level, and frequently covering the same area with the grasses, shrubs and sphagnum appear, and develop an extensive zone and a complicated plant association. In the landward edge of the last zone, coniferous trees, like the tamarack, arbor vitæ, and black spruce form the first zone in the arboreal series, and this, in turn, is replaced still farther shoreward by a border of the broad-leaved swamp trees from which, when natural conditions prevail, there is a gradual transition to upland forest. which presents a great number of species and many different and complex associations.

Ideal classification of the plant zones of the region about Walnut Lake.—Not only will the vegetation in the lakes and depressions have a zonal arrangement, but in the region of southern Michigan in which Walnut Lake lies, if ideal conditions of slope and soil exist, the entire flora would be found to be in zones around the depressions. The ideal slope would be a gentle one; the ideal soil would be a homogeneous, moderately porous loam, which would readily absorb and retain a sufficient amount of the annual rainfall to supply all plants with sufficient water for their needs. As the slope was ascended, however, the water would sink farther from the surface than at the foot, and the level of permanent moisture would be deeper below the ground surface, thus making it difficult for the shallow-rooted plants to get sufficient moisture, so that those with deep roots would displace them.

As outlined above, and if uniformly favorable temperature and rainfall conditions prevail throughout a long cycle of growing seasons, the zones would be as follows: (1) The deep water zone of Algæ and Characeæ (stoneworts), (2) Pond-weed zone, (3) Water-lily zone, (4) Bulrush zone, (5) Sedge zone, (6) Grass zone, (7) Shrub-Sphagnum zone, (8) Coniferous tree zone, (9) Swamp forest zone, (10) Hard maple-beech zone, (11) White oak-hickory zone, (12) Black oak zone, (13) Scarlet oak zone, (14) White pine zone, (15) Norway and Jack pine zone.

It must be noted, however, that with the type of soil and conditions of temperature and rainfall postulated, the elevation of the top of the slope would have to be considerably greater than any now existing in the region to have the zones of pine present. However, on a dryer type of soil, the white pine still exists in a nearly pure stand within a few miles of Walnut Lake, while near by, "Pine Lake" indicates by its name the former closer proximity of this noble tree.

Reasons for variation from the ideal arrangement.—The ideal conditions for the complete development of plant zones outlined above do not exist in Michigan, where soils are rarely homogeneous, even over a single square mile, or for more than a few feet deep, and the slopes are very irregular. The climate and rainfall are also capricious, the latter often being reduced below minimum requirement of many upland species, for periods of years and through frequently recurring cycles, thus profoundly lowering the ground water-level. This causes even aquatic habitats to vary considerably, since the water-level in lakes and marshes may be lowered several feet below the normal for a period of years by prolonged deficiency of rainfall, and thus temporarily give chances for the plants of shoreward zones to advance lakeward, opportunities which they immediately take advantage of. At such times, shrubs will invade the sedge zone, and trees the shrub zone, while the sedges and other plants more tolerant of water will make inroads along the zone left bare by the falling water of the lakes. from which the aquatic forms disappear.

The plant zones of a lake affected by the soils of the bottom.—Water and marsh plants are often restricted in distribution. and form broken and incomplete zones because of irregularities of the slope of the bottom, and the distribution of the soils on the bottom of the basin, as well as by the presence of soils whose situation or whose physical or chemical composition is unfavorable to the growth of most types of plants. Unfavorable factors such as steep or irregular slopes, exposure to strong wave action, very compact, stony, or sandy soils, or soils with too little plant food, or too much soluble mineral matter of a poisonous nature, are all likely to be present in those parts of lakes available for the growth of the seed-plants. Any of such areas may be sterile, and cause interruption in the continuity of the zones. Again, and by no means least in importance, species of the type necessary to give character to a definite area may be absent, in which case the plants of another zone, usually the one from deeper water, may occupy the place of those absent.

Application of principles to the flora of Walnut Lake.—The study of the contour map, Plate, 14 as already pointed out on a preceding page (165), shows that the slope of the basin of the lake is far from regular in those parts where vegetation can occur. In some places very steep slopes descend below the critical line of 25 feet, while over other large areas the water is less than 5 feet deep for long distances from the shores. However, the slopes from 5 to 25 feet are steep except in a few places, hence the zone of possible growth of the submerged seed-plants, and those with floating leaves, is quite narrow and also very unsymmetrical in its relations to the shore lines. The area which should be covered by partly emerged plants, bulrushes and sedges, is much broader and more conspicuous.

Relations of soils to zonal distribution.—Within the irregular marginal area, soil conditions are quite diverse, and often consist of those types which are unfavorable to the growth of aquatic vegetation. The kinds of soil have been mentioned in the descriptions of the stations and need no further discussion here, except so far as is necessary to show how they affect the development of the zonal distribution of the plants.

Marl.—It will be seen by referring to the detailed accounts of the stations, given on the preceding pages that the chief bottom soil on the zone of possible vegetation is marl. Marl is a chalky, white substance, more or less granular at the surface, but very fine-grained and compact below, which makes it physically a poor substratum for the growth of the underground propagating stems of plants. Chemically marl is even more unfavorable, since it is composed chiefly of calcium carbonate, with only traces of other mineral salts, and small and varying amounts of organic matter. This composition makes it an unfavorable soil for plants, since they require for their growth several other mineral substances besides those found in it. Besides the small amounts or total absence of necessary salts, another unfavorable feature of the marl is the fact that the included water is saturated with calcium compounds, which makes it toxic to the roots of some plants. As shown by their failure to penetrate the marl. The marl as a dominant soil is, then, capable of supporting only those plants that can grow with a minimum amount of most of the mineral salts essential to plant growth, and can also tolerate an unfavorable excess of calcium compounds. Exceptions are to be found in those plants that have roots simply for holding them in place (if we have any such) and are able to take the necessary mineral matter for their growth directly from the water through stems and leaves.

As a matter of observation at this lake, as in many others, the flora growing on the pure marl is poor in species and individuals, but when there is a slight addition of organic matter, it seems able to support a much larger number of individuals and more species. The stoneworts are generally present in numbers on marl beds, although by no means invariably so.

Stony or gravelly soils.—The stony soil present in some parts of the marginal area of the lake is another type which is adverse to the growth of plants. Its chemical composition is favorable to most of the species, but its physical composition is so unfavorable that below the water-level this soil is usually barren, and above it, supports only a simple plant association.

Black mud or impure peat.—This material is present in Walnut Lake in smaller amounts than any other. It is both chemically and physically adapted to the requirements of plants, being rich in proper mineral substances in an available form and in the necessary organic compounds, and is furthermore easily penetrated both by roots and subterranean stems. It is thus capable of supporting a relatively large number of species and many individuals in a comparatively small space. Wherever this material is present between the critical depths for marginal plants in Walnut Lake, the greatest variety and the largest numbers of plants are present.

Peat.—Peat is composed of the same kind of material (but of slightly different origin) as the black mud into which it grades some distance below water level. It is brownish in color, coarser in texture, and generally has less finely divided mineral matter than the black mud. It is formed by the growth and partial decomposition of those plants which live near, above or below, the water surface, where the soil is so wet that the dead parts cannot dry up or completely disintegrate under the action of the agencies producing decay. Peat constitutes the substratum upon which grow most of the plants of the sedge, shrub and coniferous tree zones of lakes. In Walnut Lake it is chiefly confined to very shallow water, or to areas now above the water level, and overlies beds of marl.

Effects of aquatic and marsh plant associations on their habitat.—The growth of plants on any of the types of soil mentioned above tends to produce an accumulation of plant debris upon their surface, which is not removed under usual conditions, and thus slowly raises them towards or above the water level. The ultimate end of this process is an improvement of both soil and drainage conditions, since the decayed vegetable matter is rich in plant food. The slowly rising surface of the peaty mass is eventually brought above the water, where it sooner or later dries and improves the substratum in texture through more thorough decomposition, and makes it much more habitable for plants.

It is apparent that if an accumulation of the sort just mentioned begins below the water surface, the original plant association which starts it will be displaced by another, as soon as there is sufficient up-building to improve the light and heat conditions, so that the shoreward plants can advance upon the new territory.

This new association in its turn will be driven out, when it has so modified the habitat by adding to the deposit that still another more aggressive group of plants can thrive upon it. Such changes, particularly in their early stages, take place very slowly, however, and it is only by continuous and prolonged observation, or by the study of carefully made vertical sections of the deposit that the facts pointed out can be verified. That they exist is evident when the theoretical considerations given above are applied to explain the observed facts.

The limited areas occupied by the peaty formations at Walnut Lake do not offer special facilities for securing evidence of the displacement of one plant association by another, but the contact of the peat of the sedge marshes with the underlying marl gives a record of the change from the simple associations of the stoneworts to the more complicated one of the bulrush zone, and to the still more aggressive one of the sedge zone.

The plant zones represented in the lake.—From the effects of soil conditions and steepness of slope of the bottom on the occurrence and abundance of seed-plants in lakes, it is not surprising to find in Walnut Lake considerable areas of what should be available shallow water but sparsely occupied by vegetation, and the representative plants which characterize certain zones, either wanting entirely or present in small colonies in the most favorable soils, or, at best, forming a broken zone interrupted by bare spots. Another apparent anomaly found here is the extension of the stoneworts from the deeper water practically over a large proportion of the shallow part of the lake, which, except for the marl, presents a most perfect environment for aquatic plants. Instead of having a dense growth of seed-plants with floating or partly emerged leaves, this area is largely bare of noticeable vegetation, except for scattered bulrushes, and it is only by close inspection that the carpet of stoneworts can be seen. That this condition is due to the adverse conditions presented by the marl as a soil is shown by the presence of the usual arrangement of seed-plants, where the more favorable soil conditions are found, and also by the presence of a considerable admixture of either organic matter or debris with the marl, where the higher or seed-plants grow in abundance.

Of the first nine zones, given in the list above, which might be present in the lake between the bottom and the upper limit of that portion of the basin where soil drainage is sufficiently established to preclude swamp conditions, only four are at all complete. These are the deep water, including the stoneworts, the pond-weed, the bulrush and the sedge zones. On the remaining five, some are merely suggested and others are absent altogether.

The sedge zone.—It has been pointed out in another place that the slopes about the lake are relatively steep and well drained above the level of the water, and that they come down nearly to the water line, being separated from the margin of the water by a narrow shelf of flatter land around much of the shore, which has been somewhat widened since the outlet was cut. Owing to these conditions, there is relatively little of the soil about the lake which is marshy, and, while there are quite broad expanses of sedge marsh at the west side and in places on the east side, the sedge zone, as a whole, is narrow, although extending nearly around the lake.

The sedge zone is characterized by grass-like plants, with usually triangular stems and a different arrangement of flowering and fruiting parts from that of the grasses. Several large genera and many species of plants are included under the general term "sedge," some of which grow on high ground, but the swamp and marsh types are the most conspicuous members of the family.

Many other types of plants occur in the sedge zone, some of which are larger and more conspicuous than the sedges with which they are associated; of these may be mentioned the swamp loose-strife and the cattail flag. There are also at least two types of habitat represented in the sedge zone at Walnut Lake, the wet marsh, extending into water from 1 to 2 feet deep, and the moist slope rising to the woods, or, more frequently, to the zone of pasture grasses which come from the higher land to meet it. These two were not carefully differentiated, however, since both have the same general relation to the other plant zones of the lake. The dryer parts of the sedge zone were well represented at stations 23 and 32, while the wet parts are shown in numerous figures as described below. The most conspicuous sedges of this zone were the Sartwell's, water, slender and tussock sedges, the twig-rush, which was unusually abundant, and a few spike-rushes, while true rushes, the cattail flag, and swamp loosestrife were frequent in some areas. Many other plants grew in this association, but they were not recorded. Among the figures accompanying the report, the following show portions of the sedge zone and its relations to others. Plates 16 and 19 show parts of the sedge zone of station 16, where the beach is practically covered by sedges. The bulrush zone is almost wanting along this shore. Plates 19 and 20 show the sedge zone at station 32, where there is also a stony beach and a steep bank, at the foot of which the sedge zone ends abruptly. Plate 22 illustrates the flatter type of shore, on which the sedge zone broadens out into a marsh at station 46. Plate 23 is a spring-time picture of the shore of station 3, here the sedge marsh is growing above the platform of marl, and the sedges reach out to the edge of the water.

Plate 26 is a portion of the shore of station 16, where the sedges border a beach composed almost wholly of shells; the plants are encroaching on the beach slightly. Plate 27 is another view, made in spring, of a portion of the sedge marsh of station 16, showing the sedge in winter conditions and extending into the water. Plate 28 also shows the sedge marsh at station 6 in winter condition. Plates 29 and 30 are views of station 15, showing the sedge zone in its relation to the landward shrub and tree zones and the lakeward bulrush zone. Plate 31 is another portion of the sedge marsh at the west side of the lake, and shows well the close relationship often existing between the sedge and the strictly aquatic zones, when the depth of water is sufficient to permit. In the foreground is shown the beginning of the artificial outlet where the water is deep enough to permit the growth of water-lilies close to the sedge-covered banks. Beyond the outlet the bulrush zone merges into that of sedges. Plates 35, 37 and 36, especially 35, show the sedge zone modified by swamp loosestrife; sedge plants are shown in the foreground and at the right of the picture, where the sedges form a nearly pure stand. It will be seen that from this area the sedge zone runs back toward the left behind the swamp loosestrife, two-thirds across the picture.

It is evident from these and other illustrations that the swamp loosestrife is a plant of the sedge zone, becoming dominant when present. Plates 43, 44, 45 and 46 show the sedge marsh at station 41, near the extreme southern end of the lake. Plate 52 shows another type of plant belonging to the sedge zone, although it sometimes invades the shallow water of the bulrush zone; this is the cattail, which forms a narrow zone against the swamp tree zone at station 40, and shown in the background of the picture. Plate 51 shows more clearly the relations of this plant at the same station, and it will be observed that lakeward of the denser part of the zone the plants appear scattered, and grow in the water. These may be advance guards of a general movement lakeward over the whole of the adjacent shallows. Plate 53 shows another part of this station in which the cattail grows in small stools, in shallow water covered densely with the minute fronds of a species of duck-weed and water-lily leaves. Plate 54 gives an excellent idea of the relationship between the cattail covered areas and other zones at station 40. Sedges are growing in the water on the left of the picture.

The bulrush zone.—As mentioned above, this zone is one of shallow water, occurring in depths of about 5 feet up to, or sometimes where soils are suitable slightly above, the surface, merging into the sedge zone. The bulrushes formed an almost continuous zone around the lake, although this zone was faint, or even broken, in places where conditions were adverse, as on barren shoals. It was clearly defined along the west shore at stations 15, 4 and 20, while at station 54 there was such a dense growth of bulrushes that during the summer a boat could hardly be pushed through it.

The most conspicuous plant of this zone, and the one which gives it character was the lake bulrush, but associated with it were not infrequently found the white and yellow water-lilies, pond-weeds, hornwort, water milfoil, cattail, greater bladderwort, pickerel weed, and, more frequently than any other, the stoneworts. The bulrushes grew alone on marl shoals with the stoneworts, and the other plants mentioned were only found commonly where there was a layer of black, organic mud, or ooze, above the marl, in which the plants rooted. Some species were never found except where this substratum was present. The maximum size of the lake bulrush (12 feet in length) was attained at the edge of the shoal on the east side of station 54, where the water was 5 feet deep, the extreme depth in which the plant was found growing. Among others, the following figures illustrate the relations of this zone in different parts of the lake:

Plate 47.—This is one of the best general views of a pure growth of bulrushes, showing how sparsely they grow, and, when seen in masses, how completely they shut off from view objects behind them.

Plate 17 —A picture of the beach at station 23, with a few bulrushes growing on it, above water.

Plates 29 and 30 show part of the bulrush zone of station 15.

Plates 41 and 42 give views of the relation of the bulrush and sedge zones in shallow water at station 7.

Plates 48 and 49 illustrate conditions on the margin of an opening in the bulrush zone at station 54, where the water-lilies grow around the opening and among the bulrushes.

Plate 50 is the part of the bulrush zone at station 54 where there were many nests of the black bass.

The lake bulrush is apparently somewhat indifferent to marl as a substratum, but grows larger and in denser masses where organic matter is present. As said before, it is accompanied in such places by a much greater variety of associate plants, chiefly submerged aquatics from the pond-weed zone and the water-lilies. On pure marl the stoneworts are its only associate, except for very stunted pond-weeds. A resident of the neighborhood, who was much interested in the history of the lake, reported that a few years ago the bulrushes formed a solid zone entirely around the lake, so thick that a boat could with difficulty be pushed through it. This report is in part confirmed by the abundance of dead root-stocks and underground stems of this species on most of the shoals where there are now very few living plants.

The pond-weed zone.—This was a belt of vegetation growing on the lakeward side of shoal water, between the approximate depths of 3 and 25 feet; it thus ranged from less than a hundred to several hundred feet in width.

In no case were any except microscopic plants collected from water more than 27 feet deep, and but a single seed-plant, the water weed, from more than 20 feet. The characterizing plants of this zone were the pond-weeds. of which several species were common and conspicuous, but it might well be considered the zone of submerged plants, since but few of the types growing in it have even floating leaves, the only parts to reach the surface being the flowers.

Several plants growing in this zone are also peculiar in having but the slightest attachment to the bottom, or even in some cases no roots (for example the hornwort and bladderwort). Moreover, the vegetative parts. such as buds and branches, of most of the plants of this zone are able to live indefinitely when floating about in the water with no root connection with the soil, and by virtue of this trait are scattered widely about the lake.

Besides pond-weeds, the seed-plants noted as abundant and generally distributed in this zone were, water milfoil (at least two species), water weed, hornwort and slender naias. Throughout this zone there was also an abundance of stonewort in both deep and shallow water. All of the species of this association, because of the ease with which they propagate vegetatively, were often more common in shallow than in deep water, and made luxuriant growth in such places in the bulrush zone as they established themselves, as noted above. But it was discovered that plants of these types dredged from water from 15 to 20 feet deep at station 3, on the 9th of May were all of a bright green color and in active condition, while individuals of the same species on the adjacent shoals were all apparently dead, or had not yet started to grow. It thus seems as if the conditions for plant growth were better in deep water than in shallow, at that time of the year.

At station 16, also, it was noted that, early in the season, there were no pond-weeds in water less than about 5 feet deep, but in July and August they became conspicuous in water about 3 feet deep, and were scattered, less noticeably, over the shoal in even shallower places. In the cove which constituted station 7, there was a strong development of the plants of the pond-weed zone, in shallow water and on a peaty bottom. In the spring, stoneworts and an aquatic moss, *Hypnum*, were the chief plants there, but during the early part of May other plants began to appear, and during the summer white and yellow water-lilies, water weed, hornwort, water milfoil, a number of pond-weeds, bladderwort, and water persicaria covered the bottom, but, except for the water-lilies, did not grow quite to the surface.

As early as July, at the south end of the lake, the water in the small shallow bay called station 41 was practically entirely filled by water weed, stonewort, hornwort, water crowfoot and other plants, several of which were prevalent in the pond-weed zone. The density of this mat of vegetation is shown on the right in Plate 45, just in front of the sedge growth. The little spots on the water are floating masses of green algæ with grasses entangled in them. The luxuriance of the vegetation at this spot is doubtless accounted for by the presence of from 2 to 4 feet of soft, black mud in the bottom of the bay.

Another station at which the plants of the pond-weed zone were found in quite shallow water, to the exclusion of other types, was station 54a. This habitat was a circular opening in the bulrush covering of the shoal, and had a bottom soil of partly decomposed vegetable matter, superimposed upon marl. The most abundant plants were stoneworts, reaching a length of 2 feet or more, and growing nearly to the surface of the water, water milfoil, hornwort, slender naias, greater bladderwort, while the white water-lilies grew along the edge of the bulrushes, among which were cattails, and less often the pickerel grass.

As has been pointed out above, the controlling factors in this apparently anomalous situation of these plants of the pond-weed zone are, presence of favorable soil, light and temperature conditions, readiness to migrate, and, what is more important, the absence of competition of more aggressive types.

The water-lily zone.—This was developed in but few places, and apparently only where the soil conditions were improved by the presence of organic matter. At station 31, there was an area lakeward of the swamp loosestrife covered by the leaves of the water-lilies. They grew here in water from 2 to 6 feet deep, while below them there were some pond-weed sand a dense growth of stoneworts covering the bottom. Plates 33 and 34 indicate the position of the water-lilies in relation to the marginal zone.

There was also a somewhat extensive development of water-lilies at station 26, in much the same relationship to the swamp loosestrife as at station 31, except that here was a broader zone, extending out perhaps a hundred feet to where the water was 8 or 10 feet deep. The bottom in this area, as noted elsewhere, was of black mud made up of decomposed plant remains.

Water crowfoot.—Practically a part of the water-lily association at this station was a dense growth of the white water crowfoot, which covered the water with a carpet of delicate white blossoms about the middle of June. This area is shown in Plates 37, 39, and 40, which gives its evident relations to other plant groups near it. White and yellow water-lilies were also present at station 7 (Plates 41 and 42) both in shallow water within the cove and in deeper water beyond the mouth. Here again these plants were lakeward of the bulrushes, and grew in a substratum of peaty material a foot or more thick over the marl foundations.

Another extensive development of water-lilies was at station 54a, where, as shown in Plates 47 and 49, they formed a rather dense growth along the margin of the bulrush zone. The soil of the station was a black mud above a bed of marl. There was also an unusually wide area of water-lilies at the west end of station 40, where they extended out from the shore for 200 feet to the edge of the shoal. As seen in Plates 51, 53 and 54, the water-lilies are here closely associated with cattail on the shoreward margin of the zone. The soil was chiefly a soft, dark-colored mud.

These were practically all of the areas of these plants worth mentioning, and in looking over the record given above, it seems apparent, as stated at the outset, that the water-lilies depend for their development largely upon the presence of a soil rich in organic matter, and wherever this is present in shallow water, they are likely to become conspicuous.

Other zones.—The zones of plants shoreward of the sedge zone were studied in but a desultory way, since their relationship to the special work of the investigation was remote. It may be said, however, that there were fragments of a shrub zone where conditions were favorable, and Plates 35, 37 and 38 show portions of this. The narrowness of the shelf about the lake, and the abrupt transition from this to the steep banks and clearing, are responsible for the absence of the shrub society.

No trace was found of the coniferous tree zone so common about many of the lakes of southern Michigan. The only conifers seen were the low junipers on the dry bank of the north side of the lake, at station 32 (Plates 18 and 20.)

The zone of broad-leaved swamp trees was chiefly represented at the northeast side of the lake, at station 40, and presented the usual characteristics of a wet swamp forest of the region. White elm, black ash, soft maple, swamp white oak and other swamp trees grew in the wet soil, and cast a dense shade in which, on the stools formed by the crowns of the tree roots, muskrat houses and other elevations, grew a variety of shrubs and herbs; most abundant of the latter were sedges, grasses and the touch-me-not. The pools between the trees were covered during the summer by duckweed and filamentous algæ. The conditions in this association are shown in Plates 51, 52, 53, 54 and 55. At other places along the lake shore there were small areas where conditions invited an invasion of limited numbers of trees of this zone, but they were not extensive enough to form a typical society.

Flora of the highlands.—As has been stated, this type was not examined in detail. It consisted principally of farm clearings. The distribution of the trees, now left only in woodlots, indicates that the forest was formerly dense, and the trees of good size, the kind of association found depending upon the type of soil covering a given area. The heavier soils of the moraines, the clay loams, where well watered, were covered by the hard-maple and beech, associated with red, white and bur oaks, basswood, walnut, hop hornbeam and other trees of the mesophytic or moist, drained soil type. In slightly dryer areas the hickories and white oak dominated, although in strong mixture with some of the other kinds, and on sandy loams this association passed into nearly pure white oak, then to black or yellow oak and white oak associations, and finally, on very dry sites, becoming a forest, with black and scarlet oaks, of "the oak openings" type, on such areas as the sandy, glacio-fluvial deposits, both south and north of the lake.

Portions of numerous figures show the scanty tree growth in the woodlots and pastures in the vicinity of the lake, but few of them were made to illustrate specially this type of association, and show little detail.

LIST OF PLANTS COLLECTED AT WALNUT LAKE.

In the partially annotated list given below are included all of the aquatic plants referred to in this report, and also the ones that we collected at Walnut Lake. It is not intended, however, to give an idea of the extensive flora of the region.

*Algæ.**

1. *Aphanothece stagnina* (Spreng.) A. Br. Abundant in summer at stations 7 and 41, forming, upon the bottom, blue-green gelatinous balls each an inch or so in thickness.

2. *Anabæna* sp. The material obtained was too immature for the species to be determined. It formed brownish masses on submerged plant stems at stations 40 and 37.

3. *Gloiotrichia natans* (Hedw.) Rab. Species determination doubtful as plants were immature. Taken at station 23.

4. *Scytonema ocellatum Lyng.* Station doubtful.

5. *Spirogyra* sp. A very common and conspicuous alga at stations 7, 40, and 41, where it formed a large part of the surface scum.

6. *Mougeotia* sp. Taken at station 40.

7. *Zygnema* sp. Very common; occurring mixed with *Spirogyra.*

8. *Vaucheria* sp. Abundant at station 40, where it formed tufts over the bottom.

9. *Conferva bombycina.* Taken in the ditch at station 7.

10. *Draparnaldia plumosa* Ag. Found at station 40.

11. *Batrachospermum boryanum* Sirdt. Taken in the outlet of the lake.

12. *Dichotomosiphon tuberosus* (A. Br.) Ernst. Taken at stations 33 and 47.

13. *Chætomorpha chelonum* new species. Found at station 26, on the back of a painted turtle. This has been described by F. S. Collins.†

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*The specimens of algæ obtained were identified by Mr. F. S. Collins of Malden, Mass.

†Rhodora, IX, pp. 198–199.

Diatoms.

On July 20 some bottom soil was dredged from a depth of forty feet at station 200. Like all bottom material taken from deep water, and microscopically examined, it was found to contain many diatoms. Specimens of the bottom material were sent to Dr. H. H. Chase of Linden, Michigan, who found ten species of diatoms in the material, as follows:

14. *Coccoei scutellum* Ehrb.
15. *Cyclorella meneghiniana* Kutz.
16. *Cymbella gastroides* Kutz.
17. *Gomphonema acuminatum* Ehr.
18. *Colletonema lacustre* Agardh.
19. *Melosina varians* Ag.
20. *Navicula radiosa* Kz.
21 *Navicula radiosa acuta* Grun.
22. *Nitzschia linearis* W. S. var. *tenuis* Grum.
23. *Surtella ovalis* var. *angusta* Kz.
24. *Synedra ulna* var. *lanceolata* K.

Characeæ.

Stoneworts.*

25. *Nitella* sp. This was found only in late summer. It was abundant along the mouth of the outlet, and was also noted in very shallow water near the shore at station 23.

26. *Chara contraria* A. A. Brown. The few stoneworts collected were identified as this species, with the exception of a specimen without fruits that seemed to be *Chara fragilis*. Stoneworts were very abundant in the lake, and they formed a rank growth in the shallower part of the pond-weed zone. On marl shoals small stoneworts were common, and were used by some of the sunfish as places for the attachment of their eggs. In shallow, rather quiet water, as at station 41, 7 and 54, the growth of chara was luxuriant.

Moss.

27. *Hypnum* sp. Very common at station 7, forming a thick mat over the bottom. A few fragments were also taken in our dredge at station 200. It is referred to as the "water-moss" in this report.

Horse-tails.

28. *Equisetum* sp. Horse-tails formed a large patch in shallow water at station 40, where common sunfish were nesting upon the bottom among them. These plants were also numerous in the sedge zones of some other stations, as at station 23.

*Seed-plants.**

29. Broad-leaved cattail, *Typha latifolia* L. Common at stations 40 and 54. Also formed conspicuous growths at other places about the lake, as the patches in marshes and in the sedge zone.

30. Bur-reed, *Sparganium eurycarpum* Engelm. Found in sedge zone at station 40.

31. Floating pond-weed, *Potamogeton natans* L. *Common in shallow parts of the pond-weed zone of stations 15, 24, 46 and others. It grew in patches whose position was clearly indicated by the floating leaves of the plants.

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*The specimens of these plants collected were determined by Miss Ellen Bach of the University of Michigan.

*The species marked with a * were identified by C. A. Davis.

32. Large-leaved pond-weed, *Potamogeton amplifolius* Tuckerm.* Very common; the most abundant pond-weed in the lake.

33. Various-leaved pond-weed , *Potamogeton heterophyllus* Schreb.*

34. Shining pond-weed, *Potamogeton lucens* L.*

35. White-stemmed pond-weed, *Potamogeton prœlongus* Wulf.*

36. Eel-grass pond-weed, *Potamogeton zosteræfolius* Schum.*

37. Slender naias, *Naias flexilis* (Willd.) R. & S. Abundant in the pond-weed zone in water less than fifteen feet deep. Also in shallow water at stations 7 and 41.

38. Water-weed, *Philotria canadensis* (Michx.) Britton. Abundant in the pond-weed zone, growing at all depths in this region; also in shallow water at stations 7 and 40.

39. Greater duckweed, *Spirodela polyrhiza* (L) Schleid. Abundant at station 40, growing with other duckweeds.

40. Ivy-leaved duckweed, *Lemna trisulca* L. Abundant at station 40.

41. Lesser duckweed, *Lemna minor* L. Abundant at station 40. (See Plates 53 and 55.)

42. Pickerel-weed, *Pontederia cordata* L. Patches found at stations 26, 40 and 54.

43. Lake bulrush, *Scirpus lacustris* L. An abundant and conspicuous plant characterizing the bulrush zone of the shoals of a number of stations. Besides growing in the water, it was often found on wet ground with the sedges, sometimes forming distinct patches near marsh borders. Bulrushes grew throughout the spring and summer, but only dead ones were present till about the middle of May, when the new growth became conspicuous.

The importance of the relation of bulrushes to fish life is evident, when it is recalled that black bass, rock bass, common sunfish and blue-spotted sun fish prefer for nesting the shoals where these plants abound to any others. They use the cleaned roots and root stocks of the plants, which were practically the only stable objects in the finely divided marl of the bottom, as points of attachment for their eggs. The stems also furnish shelter for the old and young, and doubtless prevent, to a considerable extent, the effect of wave action on the nests, as well as furnishing places of refuge, and feeding grounds, for many types of food fish.

44. Water persicaria, *Polygonum amphibium* L. Occasionally solitary plants of this species were found in very shallow water on a number of shoals, including those of stations 6, 7, and 31.

45. Large yellow pond-lily, *Nymphaœ advena* Soland. This species was abundant at stations 6, 7, 26, 4, 54, 41 and 51. The plant is interesting because of its very large underground stems or root stocks, and its habit of developing submerged leaves early in the season before the floating or emerged ones appear. The flowers of this plant are also often emersed on erect peduncles.

46. White water-lily, *Castalia tuberosa* (Paine) Gregge. Common at stations 26, 40, 54 and 31. This species has an interesting habit of developing tuber-like branches on the sides of the large root stocks, which, when mature, break from the parent stem and, floating about, may find favorable lodgement and develop into new plants.

47. Hornwort, *Ceratophyllum demersum* L. This species was abundant at all depths in the pond-weed zone, and at other places even in shallow water as at stations 7, 26, 54, and 41.

Its usual lack of roots, and great power to propagate from any part broken off, as well as its indifference to weak light, makes this an exceptionally wide-spread plant in any lake where it occurs.

48. White water crowfoot, *Batrachium divaricatum*, (Schrank) Wimm. This plant formed a dense growth at station 26, covering the water at one time with the white, emerged blossoms. It also occurred, although less abundantly, at stations 7, 40 and 41 (Plate 40).

49. Swamp loosestrife, *Decodon verticillata* (L.) Ell. This plant, found at stations 7, 41, 31 and 26, was one of the most interesting ones found about the lake. It formed dense tracts at stations 31 and 26, and much less noticeable ones at the others. The plant grows in wet soil or in shallow water, and is herbaceous, dying down each year to just above the water level, but is woody and perennial below it. Wherever it touches the water the bark becomes very thick and great amounts of loose, very white, thin-walled tissue, called ærenchyma, develop. This is supposed to assist the plant to live with its roots in the water. The long herbaceous branches bend over, and where they touch the water send out roots and buds which grow into branches; the stem becomes woody and covered with the ærenchymatous tissue below the water and just above, and eventually establishes itself as a new plant at about the distance from the parent that the branch reached. The branch connection dies the first winter and the new plant becomes independent. The drooping branches are shown in Plate 65, and the characteristic thickening near the ends of the branches with the roots which touch water is shown about the middle of Plate 66, while, in the background, and at either side, may be seen the well-established plants. See also report Mich. Biol. Surv., 1906, pp. 204–208th.

50. Spiked water milfoil, *Myriophyllum spicatum* L. Abundant at station 54, where it blossoms freely in July and August. This is also a slightly rooted plant, and frequently has floats with no roots.

51. Various-leaved water milfoil, *Myriophyllum heterophyllum* Michx. This plant grew somewhat abundantly in the shallow water near the swamp loosestrife border at station 26. It differs from M. *spicatum* in having well-developed, nearly entire, small leaves on the part of the interrupted flower spike above water.

52. The greater bladderwort, *Utricularia vulgaris* L. Common at stations 54 and 7, and noted at other stations less frequently. A rootless, or rarely rooting plant, with great numbers of small, bladder-like enlargements on the divisions of the finely dissected leaves, the function of which seems to be to supply the plant with nitrogen by imprisoning the small aquatic animals which find their way into them until they die, and afterwards absorbing the nitrogenous compounds resulting from their decay. The bladders have a very interesting and complicated structure for holding the animals prisoners, and a well developed system of internal glands which act as absorbing organs. For a fuller account of this interesting type of plants see Darwin *

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*Darwin, C. Insectivorous Plants.

THE FAUNA OF WALNUT LAKE.

BY T. L. HANKINSON.

As the principal purpose of this investigation was to inquire into some of the ecological factors making up the fish environment in Walnut Lake, the work on the general fauna was purely incidental to that relating to the fish. The following discussion, therefore, makes no pretense of being more than a series of notes upon the animal forms which were observed while studying the fish, or upon those types having a close ecological relation to them.

Protozoa.

The one-celled animals noted here were such relatively conspicuous types as *Arcella, Difflugia, Vorticella,* etc., seen while materials from the bottom (algæ, etc)., were being microscopically examined. The shells of *Arcella* were common among the fragments of algæ taken from the intestines of golden shiners in August, the fish having undoubtedly picked up the protozoans with the plants to which they were attached, but, nevertheless, the morsel of protoplasm constituting the animal must have served as food for the fish. *Ophrydium versatile* O. F. M. was the most noticeable protozoan in the lake, its large, greenish, jelly-like colonies being so abundant upon some of the shoals, in early summer, that they almost completely covered the bottom. In late summer this form was not seen. In the early part of August the water and plants growing in it on station 15 were blackened by great numbers of a *Vorticella*-like protozoan, which was not identified.

Sponges.

No sponges were found in Walnut lake, either by the members of the party or by Professor N. A. Harvey, of the Normal College at Ypsilanti, who made a careful search for them in the summer of 1905.

Flat Worms and Round Worms.

Parasitic worms were commonly found in the fish opened for study, both in the enteric cavity and in the body cavity. All of these organisms were preserved and sent to a specialist for identification.

Annelid Worms.

A small, few-bristled worm of this type, about an inch in length, was found abundantly in material dredged from the bottom in deep water. It was associated here with midge larvæ, which it resembled in having a reddish color; it was commonly found in whitefish stomachs with midge larvæ. Unfortunately the material sent away for determination was destroyed in transit. The leeches seen in the lake were collected and were determined by Dr. J. P. Moore of the University of Pennsylvania as follows:

1. *Glossiphonia stagnalis* (Linn.)
2. *Placobdella parasitica* (Say).
3. *Placobdella rugosa* (Verrill).
4. *Eropdella punctata* (Leidy).

Taken at stations 4, 7, 15, 32, 41 and 45. One was obtained from the stomach of a black bass caught at station 15, on May 9. Egg cases of the species were found under stones at station 45 on May 20.

5. *Dina fervida* (Verrill). One obtained from the stomach of a perch caught at station 54.

6. *Hœmopsis marmoratus* (Say). One from station 20.

7. *Pisciola punctata* (Verrill). Taken from the pectoral fin of a black bass.

8. *Macrobdella decora*. This is the largest species of leech found. It was common at station 7, in the early part of summer.

Crustaceans.

The most common crustaceans were the entomostracans, which occurred as plankton or free-swimming forms in deep water; and also about plants on the shoals, where they seemed especially abundant. In the latter habitat the smaller fish fed freely upon them, and they formed a large part of the food of the fry of the larger fish. In late summer the deep water forms of the genus *Daphnia* came to form apparently the entire food of the white-fish, as nothing else was found in their stomachs at this time of year.

The amphipods were less numerous, and only two specimens were collected; these were identified by Miss Ada Weckel as *Eucrangonyx gracilis* Smith and *Hyalella knickerbockeri* Bate.

Crayfish were common, and many were found in shallow water in the early spring as soon as the ice had left. At this season they were sometimes found attached to the gill net when it was drawn from near the bottom, where it had been set in from 15 to 30 feet of water. About 40 specimens were collected from eight different stations during the spring and summer, and all were of the same species, *Cambarus propinquus* Gir., which is the most common species in Michigan, according to Ortmann. A single specimen was taken in the lake with eggs attached to the abdomen. Two other species, *Cambarus diogenes* Gir., and *C. bartoni robustus* Gir., were caught on the outlet on May 2nd. Dr. Ortmann states that the former has been reported but once before from the state, viz., from Detroit by Faxon. Crayfish are eaten by a number of species of fish found in Walnut Lake, and form a very important, if not the chief, food of the black bass, rock bass and perch.

Insects.

As in the case of other invertebrates, no attempt was made by the field party to get a representative collection of insects from the lake and its environs, and whatever time was given to these animals was devoted to working on those forms found to be important as fish food. A special report has been written upon the aquatic insects of the lake by Dr. Needham, and is published as Appendix III of this report. A large number of specimens were also collected at the lake, in June, by Mr. A. Franklin Shull. The following are the more important notes made during the season:

May-flies.—No very large flights of adult insects were noted, although they were commonly seen about the lake. The larvæ of *Hexagenia* were eaten in large numbers by the common sunfish and to some extent also by other species. But few of these larvæ, probably because of their burrowing habits, were found elsewhere than in fish stomachs. *Heptagenia* larvæ, on the other hand, were found in large numbers on the lower surfaces of stones along the shore, and were also often taken from fish stomachs.

Dragon-flies and damsel-flies.—While adults of many species of these graceful and showy insects were numerous about the margin of the lake, larvæ were never found abundant. The few specimens of the latter collected. came chiefly from the muddy bottoms in shallow water, as at stations 7 and 41. The larvæ, however, were often found in the stomachs of rock bass and blue-spotted sunfish, less frequently in those of the common sunfish.

Grasshoppers.—These insects, while not inhabiting the aquatic parts of the stations, were abundant in the sedge and other landward zones, especially in late summer, and often fell into the water, where they were eaten by blue-gills and doubtless by other species. The insects were commonly noticed floating on the water surface, and occasionally a fish would be seen to "turn up" and capture one.

Aquatic Hemiptera or bugs.—These did not appear to be common, and but few species were collected. Among the forms obtained were back-swimmers and a small relative of the giant water bug, *Zaïtha* sp. Water striders were seen at times in quiet places near the shore, darting over the surface. Water-scorpions were frequently caught, and their eggs were common on water-lily leaves. Along the beaches, on warm days, toad-bugs were numerous.

Neuropterous insects.—Both the adult and larval forms were common. The most conspicuous of these were the adults of a species of *Sialis*, which appeared in numbers on the bulrushes during the latter part of May, and their egg masses were found attached to these plants in quantities after that time. The larvæ were found in some fish stomachs.

Caddice-flies or case-worms (so called from the interesting habit which the predaceous larvæ have of building protecting tubes or cases of sand, shells, or other fragmental material, from the bottom on which they live). Cases made of shell fragments were often seen on barren shoals, in early spring, and these larvæ were found in some of the stomachs of the fish examined. Many of these insects were collected by Dr. Needham and are more fully discussed in his report.

Flies (Diptera).—The two-winged insects were common. The type of most importance as fish food (not only of this order, but of all the insects of the lake) was the midge, *Chironomus*. Adults of this form were exceedingly abundant in the vicinity of the marshy parts of the lake shore, during the latter part of April, as mentioned in the description of station 3. See figures 12 and 13. These were identified by O. A. Johannsen as *Chironomus niveipennis*. It was, however, in the larval and pupal stages that they were generally eaten by fish. During the spring and until about June 1st, when the fully-grown larvæ were apparently more numerous and certainly more generally distributed in the lake than at any other time, they constituted the principal food-material found in the stomachs of whitefish. After this time few whitefish were collected; see tables page 251.

Sayomyia (Corethra).—This is a kind of gnat, the larvæ of which were quite common in deep water. They were taken with midge larvæ from the deep-water stations, and were sometimes found in whitefish stomachs.

Beetles.—Parts of aquatic beetles were not recognized among the food material of any fish examined, but the elytra and other parts of terrestrial beetles were often found.

Spiders.

Little attention was given to these animals, and no facts were obtained to show that they were at all closely related to the fish life of the lake. None were found in the food material from any fish, but, as they were commonly seen running over the water surface near shore, they were doubtless occasionally taken by fish, and the negative data have little significance, in view of the soft bodies of spiders, and the small numbers of stomachs examined, as well as the hasty examinations made. Water-mites were common in shallow water, and some collections of them were made.

Mollusks.

While living univalve mollusks were scarce, except in places where bottom vegetation was heavy, and rarely abundant even here, the empty bleached shells were abundant on nearly all of the marl shoals, sometimes almost completely covering them over considerable areas. There were also portions of the shore where immense numbers of these shells had been cast upon the beach and sorted by the waves, according to size, (Plate 26). Another beach of this sort formed part of station 44; from this a handful of shells was picked up and sent to Mr. Bryant Walker, who found the following species:

Limnœa desidiosa Say.
Physa sp. (too young to identify)
Physa heterostropha Say.
Planorbis bicarinatus Say.
Planorbis campanulatus Say.
Planorbis parvus Say.
Valvata tricarinata Say.
Amnicola limosa Say.
Amnicola lustrica Pils.
Pisidium (several species).

In late spring the following living snails were collected from algæ (chiefly Vaucheria):

Valvata tricarinata Say.
Amnicola limosa Say.
Planorbis parvus Say.
Pisidium sp.

On August 6th, small snails, *Limnœa desidiosa* Say, were found in large numbers near the shore in very shallow water at station 32. Bivalve mollusks, or "mussels," were common, but not conspicuous; the smaller ones were sometimes found in shallow water, but large ones seemed to be limited to deeper parts of the shoals, near the landward margin of the zone of pondweeds. These were apparently of one species, which was identified by Mr. Walker as *Anodonta grandis footiana* Lea. Shells and fragments were sometimes found in fish stomachs. Glochidia were found attached to each of the ten specimens of Johnny darters taken at station 49, on May 22, and also on the specimen of the same species taken at station 41, on April 27.

Amphibians.

Incidentally to the work of studying the fish, the following amphibians were collected or noted:

1. American toad, *Bufo americanus* (Le Conte).—Toad eggs were abundant in the marsh (station 36), on April 12th and April 26th, and the animals were heard about the lake until about the middle of May.

2. Common tree-toad, *Hyla versicolor* Le Conte.—This noisy species was heard calling from the woods, orchards, farm-yards, and other places in the neighborhood of the lake. On May 16th, they were noticed abundant about a water-hole in an orchard a few rods from the lake, on the high ground south of the strip of timber forming part of station 23. The chorus of their voices from this place could be heard for a long distance, and they were doubtless breeding in the pool.

3. Leopard frog, *Rana pipiens* Schreber.—This was the commonest frog. It made its home chiefly in the marshes and sedge areas of the lake, and was

not seen on higher ground, and only occasionally in the lake. On April 13th a specimen of this species was caught in the fyke net, which was set at station 200, several feet from shore, and in about 40 feet of water. On the 18th of April, eggs were found in the lake, where the water was but a few inches deep at station 44, about 30 feet from the shore, while on the 20th a mass of eggs was found attached to an isolated swamp loosestrife plant, in five feet of water at station 31. From these observations it is apparent that the species enters the lake occasionally, but evidently not in numbers.

In early April, immediately after the ice melted, leopard frogs became common and noisy in the marshes and about them, and the first eggs were found on April 8th, in the marshy part of station 46, in water 8 inches deep and of a temperature of 8.5° C. These eggs were unsegmented and were probably very recently deposited. On the 11th and 12th of April this species and its eggs were very numerous in a small marsh at station 36, and individuals were also seen spawning at that time. Frog eggs were often found during April, and small tadpoles, probably of this species, became abundant in the latter part of the month, in low, wet, sedge-covered places. After this time the adult frogs ceased calling and were not heard in May.

4. Green frog, *Rana clamitans* Latreille.—An abundant frog, being noted chiefly during the late summer at stations like 7, 40 and 41, where submerged plants were abundant, and where large specimens were sometimes found. Transformation stages were caught in the ditch at station 7, in July, and numerous small adults of the species, just transformed, were found on the wet beach at the west end of station 23, in August, while their tadpoles were common in shallow water on the same shoal.

Reptiles.

1. Garter snake, *Thamnophis sirtalis* (Linnæus). Common about the lake on both high and low ground.

2. Water snake, *Natrix fasciatus sipedon* (Linnæus). This form appeared to be rare, and only three were taken in the entire season.

3. Blue racer, *Bascanion constrictor* (Linnæus).—But a single specimen of this snake, a large one 54 inches long, was taken. It was caught in the timber zone of station 23, on May 16th.

4. Milk snake, *Lampropeltis doliatus triangulus* (Boie).—On August 24th a specimen of this snake was found at station 31.

5. Snapping turtle, *Chelydra serpentina* (Linnæus).—Specimens of this turtle were sometimes caught in the fyke net, but the species was not common. The largest one noted was caught at station 6, on May 4th, and had a shell 11 inches long and 8 inches wide.

6. Musk turtle, *Aromochelys odoratus* (Latreille).—This was the most common turtle in Walnut Lake, and large numbers were seen crawling on the bottom, both on shoals and in the pond-weed zone, especially during the spring. On June 25th, 91 eggs of the musk turtle were found buried slightly above the water level in the walls of a muskrat house at station 40, and 70 were taken from another at station 7 (Plate 67).

7. Blanding tortoise, *Emydoidea blandingi* (Holbrook).—Taken with the painted turtle and musk turtle on the shoal of station 16.

8. Western painted turtle, *Chrysemys marginata* (Agassiz).—Individuals were commonly seen, although the species was not abundant in the lake. The stomach of a specimen taken July 2nd, at station 26, was found dis-

tended with the leaves of some small-leaved pond-weed, probably *Potomogeton pusillus* L. or *P. foliosus* Raf. C. A. Davis, who identified the leaves, says regarding them, "It seems as if they had been scooped up from a mass of drift material, such as sometimes accumulates in shallows, rather than bitten off by the animal." With this material were found water milfoil buds, bunches of filamentous algæ, and fruits of the slender naias.

Birds.

No especial effort was made to study the birds of the region. Aquatic forms and others that might affect fish life were noted, and a list of the species observed, with a few notes upon them are given below. Only the forms that could be positively identified are listed.

1. Pied-billed grebe, *Podilymbus podiceps.*—Throughout the summer, two were often seen in the vicinity of station 26.

2. Loon, *Gavia imber.*—Often seen on the lake in late spring.

3. American bittern, *Botaurus lentiginosus.*—A few were observed about the lake at different times during the summer. Often heard "pumping" on the marshy point on the west side of the lake.

4. Least bittern, *Ardetta exilis.*—Occasional in late summer at station 7.

5. Great blue heron, *Ardea herodius.*—A single individual was often seen at different places during the summer.

6. Green heron, *Butorides virescens.*—Common throughout the summer.

7. Black-crowned night heron, *Nycticorax nycticorax nævius.*—One or two noted during the summer.

8. American coot, *Fulica americana.*—One seen in late spring at station 12.

9. Greater yellow-legs, *Totanus melanoleucus.*—Common in May; often present in large flocks on the beaches.

10. Solitary sand-piper, *Helodromas solitarius.*—One seen at station 40 on May 3.

11. Spotted sandpiper, *Actitis macularia.*—Common in summer.

12. Kildeer, *Oxyechus vociferus.*—Common in large flocks, especially in late summer.

13. Belted kingfisher, *Ceryle alcyon.*—Common.

14. American crow, *Corvus brachyrynchos.*—Common. A nest was found in the timber zone of station 23. Often seen feeding along shore of lake.

15. Red-winged blackbird, *Agelaius phœniceus.*—Abundant and conspicuous about the marshes. Especially common at stations 54, 40 and 7.

16. Swamp sparrow, *Melospiza georgiana.*—Common in marshes about the lake. Often heard singing in early summer.

17. Barn swallow, *Hirundo erythrogaster.*—A very abundant species throughout the summer. Hundreds often seen over the lake, capturing insects on the wing. They were also found roosting among the rushes at station 54. The stomachs of two caught in an insect net contained many insect fragments, chiefly those of beetles, but no remains of aquatic species were noted. These birds were sometimes seen upon the beach near the water edge.

18. Tree swallow, *Iridoprocne bicolor.*—Often seen with the barn swallow flying over the lake.

19. Waxwing, *Ampelis cedrorum.*—Common along the edge of the woods near the lake, at station 32, in early summer.

20. Long-billed marsh wren, *Telmatodytes palustris.*—Commonly heard at stations 54 and 7 in early summer.

Mammals.

Muskrat, *Fiber zibethicus* (L.).—This is the only mammal noted that could be considered an inhabitant of the lake. It was often seen swimming near shore, and its houses were common at stations 40 and 54. There was one also at station 7 and a few at 41. This animal undoubtedly has much effect upon the fish life, since it removes quantities of vegetation from certain areas of the lake, and in other ways disturbs conditions in the shoal water. Observations made in July and August made it appear that a curious effect, noted in many places where the bulrushes were dense, was produced by the muskrat. Many rushes were cut off close to the water surface. This was first attributed to ice action in the spring, but this cause was made improbable by the fact that rushes were being cut down in late summer in large numbers. A farmer boy living near the lake stated that these animals cut off the young bulrushes a few inches above the surface of the water, and gather them into rafts or platforms upon which they sit while eating. A large number of such rafts, as shown in Plate 68, were found at station 54. Some of the bulrush stubble possibly produced in this way is shown in Plate 69.

SUMMARY AND CONCLUSION.

BY T. L. HANKINSON.

In our opinion the results of the work done at Walnut Lake fall into two classes: (1) the determination of the fish life, and the habits of the species, and (2) the study of the lake as a fish environment. The results of the first class are so diverse that no generalizations are advisable, and it only remains to sum up the environmental conditions presented by the lake, and their effect upon the fish life. Walnut Lake may, in the terminology of Forel, be classified as a lake of the temperate type and second order, as the temperature of the surface water varies widely both above (summer) and below (winter) the point of maximum density of water (39.2° F.), and the bottom temperature undoubtedly undergoes slight fluctuations. These two conditions are the almost necessary results of the geographic position of the lake in the temperate zone, and its depth.

As may be seen from the contour map, the basin consists of a shallow marginal shelf whose outer margin has an approximate depth of 25 feet, and lakeward of which the bottom drops rather regularly to 70 feet and then in places to a little over 100 feet. Briefly, the shoals are marl, and covered by a sparse growth of vegetation, but the margins, from depths of 5 to 25 feet, support a rather luxuriant growth of aquatic plants; lakeward of this zone, the bottom has only a very scanty plant growth, consisting principally of diatoms. According to Forel the limit of extensive plant growth marks the limit of the littoral region, and the almost plantless area within this zone should be classed as the abyssal region. On this basis the boundary between the littoral and abyssal regions in Walnut Lake is approximately marked by the 25-foot contour.

The conditions that characterize the littoral region are: shallow water, a variable temperature approximating that of the air, a relatively good development of vegetation, a considerable abundance of invertebrates, abundance of light and oxygen, considerable wave action. The littoral zone, as has long been noted, is usually divided into a large number of minor habitats by variations in the influence of the environmental factors such as wave action, soil composition, depth, etc. Where other factors are generally uniform the increasing depth off shore breaks up the environment into smaller units, as shown by the concentric zones of aquatic plants. Just how far the local distribution of fish corresponds to the habitats indicated by the plants cannot be determined until many more observations are at hand, but it is evident from our observations that the littoral region supports a characteristic fish fauna. According to our observations it is the principal habitat of the smaller species, such as the blunt-nosed minnow, straw-colored minnow, barred killifish, Johnny darter, least darter, golden shiner, *Etheostoma iowæ*, Cayuga minnow, and black-chinned minnow, and furthermore furnishes spawning grounds for such larger fish as the sunfishes and bass. The fish life is apparently adapted to these conditions. The small fish find protection in the vegetation, and it seems fair to assume that the larger fish must of necessity spawn here, as the lower temperatures and lack of oxygen of the depths could only retard the development of the eggs. The observation that in Walnut Lake the principal home of these species is the pond-weed zone, is an interesting one. It may be that the more abundant vegetation in this habitat affords better protection than do the barren shoals, or it may be that the shoals are so frequently unfavorable, owing to the variation in wave action, temperature, etc., that the fish occupy the relatively more stable conditions of the pond-weed zone as a permanent habitat, only visiting the shoals.

The conditions in the abyssal region are quite the reverse of those in the littoral zone. The temperature must be rather constantly about that of the maximum density of water, water perpetually calm, the light feeble, vegetation scanty, pressure considerable, and the animal life abundant. As a rule the abyssal region is characterized by an abundance of nitrogenous matters and a lack of oxygen, owing to the fact that all pelagic forms, when they die, sink to the bottom and decay, thus tending to transform the proteids into simpler compounds (the nitrates) with a consumption of oxygen. Owing to the dearth of cholorophyll bearing plants these nitrogenous compounds cannot be converted into protoplasm again with a renewal of the oxygen in the water, so that there is in general a dearth of oxygen until the spring and fall circulation periods, when the aerated water of the surface is mixed with the water rich in nitrogen from the depths. As Prof. Reighard has pointed out (see p. 195), there is, relatively speaking, considerable oxygen in the deep water of Walnut Lake during the summer stagnation period, so that we may expect that there is relatively little decomposition taking place on the bottom, a circumstance probably due to the fact that there is little plankton in the lake.

The fish of the abyssal region of Walnut Lake are also characteristic, the whitefish and common sucker being found here apparently more than elsewhere. It follows from this that the whitefish is adapted to the conditions in the abyssal region of this lake, as shown on a preceding page (200), and possibly will do well only under these conditions; at any rate, this hypothesis should govern future plantings, until the subject has been investigated more fully.

APPENDIX I.

DESCRIPTION OF APPARATUS AND METHODS OF RECORDING OBSERVATIONS.

BY T. L. HANKINSON.

While the description of apparatus and other forms of equipment and the methods used in recording observations are of little interest to the general reader, it has been thought best to insert a short account of these for the benefit of teachers and investigators who have special interest in this kind of work, and who may wish exact information concerning the apparatus and methods employed.

The equipment may be classified under three heads:

(1) Collecting.
(2) Observing.
(3) Recording.

I. *Collecting Apparatus.*

(1) *The Boat.*—The boat used was about 16 feet long by 4 feet wide; it was flat-bottomed and exceedingly well adapted to the kind of work done. It was borrowed from the Michigan Fish Commission, through the kindness of Superintendent Seymour Bower and Mr. J. L. Brass, who sent it from the Bass Hatchery at Drayton Plains.

(2) *Fyke nets.*—The fyke net consists essentially of a long bag net, or funnel, distended by hoops, from the mouth of which vertical nets (the leaders or wings) extend on outward on both sides. The bag-net tapers gradually to small size, and may have a trap towards the smaller end. Two nets of this type were used, the one borrowed from the Zoological Laboratory of the University of Michigan had a one-inch mesh, had a funnel about 20 feet long and 3 feet high at the mouth, and 40 foot wings. This net was very useful in collecting fish from shallow water stations. The second net of this type was purchased for this work, and differed from the other in having the funnel but 12 feet long and 5 feet high, while the wings were each 60 feet long. The larger end of the funnel and the wings were of inch mesh, but the smaller end of the funnel was of half-inch. The chief use made of the net was in the deeper parts of the pond-weed zone. Plates 70 and 71 show these nets.

(3) *Gill net.*—This is essentially a long, straight, rectangular net of large mesh, weighted on the lower side and buoyed above, so that when in use it stands upright in the water. When set it is sunk to the bottom, its position marked by buoys, and it catches the larger fish by entangling them when they try to get through the meshes.

Three nets of this type were available, but of these only one was generally used. This was the property of the State Biological Survey, and was 300 feet long, 7 feet deep, and of 2½ inch mesh. It was the only apparatus which was a success in catching fish in the deepest water of the lake. The other two gill-nets were borrowed from the U. S. Fish Hatchery at Put-in-Bay, Ohio, and were 200 by 6 feet; one had one-inch and the other a ½-inch mesh. These were used but little.

(4) *Drag Seines.*—This seine is a long net, sometimes rectangular, sometimes tapering at the ends, which is weighted at the lower edge and buoyed at the upper edges. Strong ropes are attached to the ends of the net, with

which it is drawn. Various types of these seines are in use by fishermen, but all are used to enclose a larger or smaller area of water temporarily, and then drawn. The drag net is usually set in shallow water and dragged ashore along with such fish as are enclosed by it. Three large nets of this sort and two small ones were used. The largest was borrowed from the U. S. Bureau of Fisheries and was of inch mesh, 100 feet long, 12 feet wide at the middle and tapering to 8 feet at the ends. A second net was the property of the State Biological Survey, and was of inch mesh, and 60 by 12 feet. The third large net was a minnow seine, purchased in the summer to make collections of the small fish in the pond-weed zone. This was of ⅜-inch mesh, 50 feet long, 12 feet high, tapering to 8 feet at the ends. Minnows and other small fish were caught in shallow water near shore by "Common sense" minnow seines, made of coarse mosquito netting; two of these, 20 by 4 feet, and 8 by 4 feet, respectively, were used.

(5) *Trammel net.*—This type consists of three nets fastened together at the edges, the outer two of large twine and coarse mesh, the mid-one somewhat larger than the others, so that it is loosely held in folds between them, and is of finer twine and small mesh. Fish pass through the large meshes readily, only to be entangled by the finer net within, which, because of its fulness, pushes readily through the coarser meshes and forms pockets which hold the fish securely. The trammel-net used was 100 by 6 feet; the mesh of the outer nets was 8 inches, and of the middle one one inch; this was used for shallow water, as it could be used regardless of the nature of the bottom or the density of vegetation growing there. Plate 72 is of this net set at station 54.

(6) *Dip nets.*—These are too well known to need description. Several were used for collecting fish and other animals.

(7) *Set-line or Trawl.*—This is a well-known device for exposing a larg- number of baited hooks for some time in places favorable for fish. It cone sists of a stout line, to which hooks with leaders of proper length are tied at regular intervals. In use, this line of hooks, properly baited, is stretched at a suitable distance above the bottom and marked by buoys. From time to time the fisherman examines it, rebaits the bare hooks, at the same time taking off the fish caught. Such a set-line was rigged and set for several weeks at station 225, but with few results, a whitefish being the only fish caught.

(8) *Dredges.*—This useful type of collecting implement consists essentially of a bag-net, the mouth of which is held open by a metal framework, to which is attached a rope for dragging the net along the bottom. Two of these, a "triangle dredge" and a circular one, were borrowed from the Michigan Fish Commission. The "triangle dredge," is so-called from the triangular shape of the frame to which the net is attached. The one used was a bag-net of scrim, about 2 feet deep, the mouth of which was held open by a heavy, equilateral triangular iron rim, the sides of which were about 2 feet long. The front edges of the rim were provided with saw-like teeth bent outward, so that when dragged along the bottom they would stir up the mud and such organisms as were in it, so that some of them would be taken in the net. The dredge was kept upright when in use by iron rods each 3 feet long, extending backward from each angle of the triangle, parallel with the direction of the net. This was the dredge used most, and was efficient in getting large samples of bottom material and the small animals living in it. A second dredge, which was little used, had a circular metal

mouthpiece without teeth, and four bars, like sled runners extended back from it.

(9) *Plant hooks.*—These, as the name implies, are hooks for dredging plants from the bottom in deep water. They were similar to those described by Pieters*, and were made as follows:

Four large hooks of heavy, strong wire were placed in one end of an iron pipe 18 inches long, at right angles to each other, and a piece of the same wire bent to form a ring in the other end, and the pipe was filled with melted lead. A line was fastened to the ring, and the hook was used for collecting plants from deep water being very efficient for the purpose, as shown by Plate 73.

A small bag-net about 6 inches in diameter and 2 feet long was fastened to the hooks, so that it dragged behind them to catch insects and other organisms disturbed by the hooks, and some of the mud stirred up by it; this was a useful addition to the drag. The combined apparatus was called "the hook and net drag."

(11) *Birge net.*—This was used but a few times in making small collections of plankton.

(12) *Soil sampler.*—This was a tool similar in form to that figured by Pieters†, and was made from a tin funnel and an iron pipe.

(12) *Walker dipper.*—This name was given to a copper dipper of about a quart capacity, having a bottom of wire cloth, and a handle with a screw clamp by means of which it could be quickly fastened to any convenient pole. It is the invention of Mr. Bryant Walker, who has long used it in collecting mollusks in shallow water, and who presented two of them to members of the survey party. There were very useful for making collections where the water was shallow.

(13) *Trap lantern.*—An acetylene bicycle lamp with funnels and reflectors, below which was a vessel containing potassium cyanide, was used to attract and capture flying insects at night. The apparatus was hung to trees or posts, near the lake or the outlet, and left over night. This lamp was invented by Dr. J. G. Needham.

(14) *Sieve net.*—This is a rectangular tray of heavy tin, having a long handle running at right angles with the bottom, which was made of wire netting. It was used like a hoe in shallow water, and was made for Dr. Needham's use after a design of his own.

II. *Equipment for making observations.*

1. *Water glass.*—This is a simple apparatus, consisting of a pane of glass set tightly into a deep frame which will keep out water. Of the four used, two were ordinary galvanized iron pails, with glass bottoms, and two were metallic trays, also with glass bottoms; one of the latter was 1½ feet and the other 3 feet square.

These glasses were placed on the surface of the water, and by looking through them, the effect of waves, or reflection and polarization, from the water was done away with. Under ordinary conditions of lighting objects 12 or 15 feet below the water surface could be distinctly seen. A wooden box with a pane of glass tightly set in the bottom will answer as well as the more expensive metal ones, and will furnish a means of obtaining a great amount of information regarding the habits of aquatic animals to any one living near a lake or stream.

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*Pieters, A. J. Plants of Western Lake Erie. U. S. F. C. Bulletins, Vol. XXI. Washington, 1901, pp. 57-79.

†Pieters, A. J. loc. cit., p. 58.

2. *Searchlight.*—This was loaned by the U. S. Bureau of Fisheries, and was found valuable for getting records of fish in shallow water at night.

3. *Thermometers.*—A series of standard chemical thermometers, obtained from the Bausch and Lomb Optical Company, were used in taking deep-water temperatures, and a Negretti-Zambra deep sea thermometer was borrowed from Professor A. E. Birge of the University of Wisconsin, and used for a few days.

4. *Thermophone.*—This instrument was purchased for the investigation, but had been used only a short time at the opening of the season when it got out of order, and it was late in the season before it could be repaired, so but few readings were made with it.

5. *Anemometer.*—A small portable hand instrument, owned by the State Biological Survey, was constantly used to make observations on the velocity of the wind whenever other observations were made.

6. *Aneroid barometers.*—A pocket aneroid, the property of the Michigan Geological Survey, was used to obtain daily record of the atmosphere pressure near the lake level.

7. *Barograph.*—This instrument also belonged to the Michigan Geological Survey, and was kept running continuously from about May 1st to the middle of August.

8. *Turbidimeter.*—The standard candle turbidimeter, of the pattern used by the Bureau of Hydrology of the U. S. Geological Survey, was furnished by the Michigan Geological Survey, and used to measure the amount of turbidity of the water at various times.

9. *Colorimeter.*—This also was of the type used by the Bureau mentioned above, and was a part of the equipment furnished by the Michigan Geological Survey.

10. *Aquaria.*—Four aquaria were borrowed from the U. S. Bureau of Fisheries and were used for making photographs of live fish, for rearing insects, and for keeping aquatic animals which were under special observation. The aquaria were supplied with water from a metal watering tank, elevated somewhat above them, into which the water was pumped from the outlet of the lake. The position of this tank and arrangement of the aquaria are shown in Plate 74.

III. *Equipment for making records.*

1. *Field notes.*—The loose-leaf system of records was used, and the sheets for the day were carried in aluminum holders, which were found convenient for the purpose. The form reproduced below was used in recording observations at definite stations.

Locality.. Sheet............
Station..........Date..........190..Observer........Time of day......
Air temperature..............Wind, direction......velocity............
Water temperature, surface........bottom........other depths.........
Sky............Light............Air pressure.........................
Precipitation.........................Turbidity.....................
Bottom..
(a) Plants

(b) Invertebrates
(c) Vertebrates other than fishes

(d) Fishes observed but not taken

(e) Fishes taken: Method......................Nets..................
Hauls.........................Depths..............................
Names

Further notes on sheet...

2. *Cameras.*—A 4 x 5 reflex camera was used to make photographic notes to accompany the written ones, instead of sketches. For larger landscape work, a 6½ x 8½ and a 5 x 7 camera were used. For making pictures of living fish in the aquaria a 5 x 7 "graflex" camera was available on several occasions. Altogether several hundred photographs were made during the season, some of which are used to illustrate this report.

IV. *Miscellaneous equipment.*

1. *Tents.*—Two small tents, belonging to the Michigan Geological Survey were used for storage and field laboratories, for the rougher work.

2. *Preservation methods.*—The fish collected were preserved in formaldehyde according to a method used by R. E. Richardson of the Illinois Laboratory of Natural History. The fish were thoroughly hardened by leaving them in a 10% solution of formalin for a few days, after which they were transferred to a 2% solution for permanent preservation. Insects and a few other specimens were placed in alcohol, but relatively very little of this preservative was used.

Plant specimens were either pressed or preserved in 2% formalin solution. Large milk cans were used for storage of fish specimens, and the usual forms of glass vials, bottles, and jars were employed for small and delicate material.

APPENDIX II.

DATA ON STOMACH CONTENTS OF FISH TAKEN IN WALNUT LAKE.

BY T. L. HANKINSON.

The following tables, while not in any way pretending to give a complete account of the numbers of fish caught and examined, may give some indication of the food of the food-fish, especially the whitefish, thereby giving some information as to what is a proper habitat in which they will thrive. Other data regarding the same subject will be found in the section relating to various stations, with other similar facts which would not admit of tabulation.

Table 1.—Data relating to fish taken in fyke net in the pond-weed zone, station 3.

Name of fish.	Date.	Time of day.	Length of fish, inches.	Food.	Remarks.
Common sucker.......	April 9	9:45 A.M.	20		All fish taken on April 9, in from 10-15 ft. of water.
Rock bass............	April 9	9:45 A. M.	6	Much insect material; apparently mostly midges. A dragon-fly larva.	
Yellow perch..........	April 9	9:45 A. M.		3 Hexagenia larvæ and about 200 Daphnia.	
Common sunfish......	April 9	9:45 A. M.	6	Insect material. Nature?	
Yellow perch.........	April 10	9:30 A. M.	5½	Daphnia, with undeterminable material.	
Yellow perch..........	April 10	9:30 A. M.	6	Midge larvæ and Daphnia.	
Yellow perch..........	April 12	8:00 A. M.	4¾		
Blue-gill..............	April 12	8:00 A. M.	3	Many midge larvæ; 16 counted.	
Large mouth black bass	April 12	8:00 A. M.	8½	Stomach empty.	
Common sunfish.......	April 13	8:00 A. M.	3¾	Midge larvæ, caddice worms, an amphipod.	
Yellow perch..........	April 15	8:00 A. M.		Midge larvæ.	All fish taken on April 15, in from 12½ ft. of water.
Yellow perch..........	April 15	8:00 A. M.		Midge adults or pupæ.	
Yellow perch..........	April 15	8:00 A. M.		Midge larvæ and pupæ.	
Yellow perch..........	April 15	8:00 A. M.	6	10 midge larvæ and 6 pupæ	
Yellow perch..........	April 15	8:00 A. M.	5¾	May-fly larvæ and undeterminable material.	
Rockbass.............	April 15	8:00 A. M.	8		
Yellow perch..........	April 17	9:00 A. M.	5	65 midge pupæ.	
Yellow perch..........	April 20	2:00 P. M.		85 pupæ and adults of midges	
Yellow perch..........	April 20	2:00 P. M.		98 midge pupæ.	

Table 2.—Data regarding fish taken and examined at station 6.

Name of fish.	No. taken.	Date.	Length of fish, inches.	Food.
Common bullhead	1	April 28.	4 5-16	Crayfish, Hexagenia larvæ.
Yellow cat	2	April 28.	11¾, 12	Empty.
Common sucker	5	April 28.	15 to 18	Not examined.
Common sunfish	1	April 28.	7½	35 Hexagenia larvæ.
Blue-gill	14	April 29.	8 to 9	Midge adults, pupæ and larvæ, Hexagenia larvæ, *Sialis* larvæ, crayfish, dragon-fly larvæ, leeches. May 2—Hexagenia larvæ, Heptagenia larvæ. May 9—Caddice worms and Hexagenia larvæ.
Large-mouth black bass	1			A small perch, 4½ inches long.
Wall-eyed pike	1			Empty.

*Table 3.—Data relating to fish taken at station 15.**

Name of fish.	No. taken.	Date.	Length of fish, inches.	Food.
Blue-spotted sunfish....	1	May 4.	5¾	A small crayfish.
Common sunfish.......	2	May 4.	6¾	6 midge larvæ.
Blue-gill..............	3	May 4.	8¼	A crayfish 1 inch long, 3 caddice worms, 54 midge larvæ; the latter formed about 30% of the stomach contents.
Common sunfish.......	3	May 9.	6	(a) 8 heptagenia larvæ, 3 hexagenia larvæ, 3 midge larvæ; (b) 12 heptagenia larvæ, 6 caddice worms, 3 midge larvæ, 3 leeches; (c) Fragments of a crayfish, with much undeterminable insect material.
Large-mouth black bass.	1	May 9.	9½	A number of small unidentifiable fish.
Common sunfish.......	15	June 9.		(a) Dragon-fly larvæ, 10 heptagenia larvæ, 2 hexagenia larvæ, 2 midge larvæ. (b) 17 heptagenia larvæ, 8 hexagenia larvæ, 4 caddice worms, a small crayfish and a leech.
Perch.................	400	April 23.	2 to 10½	
Yellow cat...........	3	" "	9½ to 11	
Common bullhead......	1	" "	12	
Rock bass............	1	" "	7½	
Common sunfish.......			6	
Perch.................	124	April 24.	4 to 9½	
Perch.................	525	April 25.	2 to 6	
Wall-eyed pike........	2	April 26.	26	1 with perch 4 inches long, other empty.
Whitefish.............	1	April 26.	13½	Several midge and May-fly larvae
Common sucker........	3	" "	17½	Larvæ.
Whitefish.............	1	" "	19	Mostly midge larvæ.
Large-mouth black bass.	1	" "	15	Empty.
Wall-eyed pike........	1		19	Empty.
Common sucker........	1	Later same day	16½	
Whitefish.............	1	Later same day	18½	A few whitened snail shells.
Common sucker........	1	July 6.	17½	
Yellow perch..........	11	Aug. 11.	4 to 5½	
Large-mouth black bass.	5	" "	2½ to 3	
Blue-gill..............	5	" "	2½	
Blue-spotted sunfish....	2	June 9.	7 to 8	(a) Three small crayfish, dragon-fly larvæ. (b) A small fish so far digested as to be unidentifiable.

* First six listed caught by a trammel net; the last four by drag seine, and others by gill net or fyke net.

*Table 4.—Data relating to fish taken at station 4.**

Name of fish.	No. taken.	Date.	Length of fish, inches.	Food.
Pike	3	April 3.	12 to 17	Perch.
Perch	1		9½	Empty.
Common sunfish	3		5 to 7	4 larvæ and 4 adult midges, 2 hexagenia larvæ and a small leech.

* Caught by drag net.

Table 5.—Data relating to fish taken at station 7.

Name of fish.	Date.	Length of fish, inches.	Food.
Blue-gill	April 25.	8½	Midge larvæ and undeterminable material.
Rock bass	May 1.	9	2 crayfish.
Black bass	May 1.	4½	1 crayfish.
Black bass	May 1.	4¼	2 crayfish.
Common sunfish	May 1.	9¾	2 caddice worms, 2 caddice worm pupæ, 9 hexagenia larvæ, 1 heptagenia larvæ, 2 crayfish.
Common sunfish	May 1.	6	1 dragon-fly larvæ, 1 heptagenia larvæ, 3 hexagenia larvæ.
Common bullhead	May 1.	13¼	2 dragon-fly larvæ, 32 hexagenia larvæ, 2 midge larvæ 1 minute mussel.
Black bass	May 1.	9¼	1 small crayfish, miscellaneous insect material, water moss.
Blue-gill	May 4.	8½	1 hexagenia larvæ, 2 heptagenia larvæ, 105 midge (?) larvæ.
Common sunfish	May 4.		16 hexagenia larvæ.
Black bass	May 4.	9	5 small crayfish.
Blue-spotted sunfish	May 4.	9	4 small crayfish.
Blue-spotted sunfish	May 5.	2¼	1 small crayfish and a leech.
Blue-spotted sunfish	May 5.		1 leech.
Blue-gill	May 5.	5½	May-flies, midge pupæ and amphipods.
Black bass	May 6.	9½	Crayfish fragments.
Common sunfish	May 6.		8 Hexagenia larvæ, 2 heptagenia.
Rock bass	May 7.	1¾	Midge larvæ.
Tadpole stone-cat	May 23.	1¼	Insect fragments: legs, heads, etc.
Rock bass	May 30.	9½	Crayfish fragments.
Black bass	May 31.		
Wall-eyed pike	June 12.	22¼	Empty.
Common bullhead	June 13.		Crayfish fragments.
Yellow cat	June 13.	11	Crayfish fragments.
Black bass	June 13.	14½	Crayfish.
Perch	June 27.	1¼	Copepods.
Mud minnow	July 1.	2	Entomostracans and hydrachnids.
Golden shiner	July 8.		Filamentous algæ and midges, entomostracans, Arcella shells.
Golden shiner	July 8.		Filamentous algæ, Arcella shells.
Mud minnow	July 11.	3¾	Insect material, entomostracans.
Yellow catfish	July 11.	3¼	Midge larvæ and May-fly larvæ.
Common bullhead	July 11.	1½	Midge larvæ, entomostracans.
Black bass	July 11.	1½	Entomostracans.
Golden shiner	July 16.	3	Filamentous algæ, apparently all spirogyra.
Golden shiner	July 16.	3	Same as last.
Golden shiner	July 16.	3½	Same as last.
Blue-gill	July 16.	2¼	Insects and entomostracans.
Common sunfish	July 16.	2¾	Midges and other insects.

Table 6.—Data relating to fish taken at station 41.

Name of fish.	Date.	Length of fish, inches.	Method of capture.	Food.
Large-mouth black bass...	May 31.	2½	Minnow seine	A least darter.
Black bass..............	May 31	2½	" "	Two least darters.
Blue-spotted sunfish......	May 31.	3½	" "	Dragon-fly larva.
Blue-spotted sunfish......	May 31.	1½	" "	Miscellaneous insect material, legs, etc. Some hydrachnids.
Barred killifish...........	May 31.	1¼ to 3		Insect material, midge larvæ.
Perch..................	June 26.	1⅜	" "	Entomostracans.
Perch..................	June 26.	1⅜	" "	Entomostracans, with badly digested other food.
Rock bass..............	June 26.	2⅜	" "	Crayfish fragments.
Rock bass..............	June 26.	2½	" "	Crayfish fragments.
Least darter.............	June 26.	1⅛	" "	Entomostracans and insect material.
Perch..................	June 26.	4	" "	Several small crayfish, each about ⅜-inch in length. Part of a small fish, which was about ½-inch long.

*Table 7.—Data relating to fish taken at station 54.**

Name of fish.	Date.	No. taken.	Length of fish, inches.	Food.
Common bullhead........	May 1.	2	11, 17	Crayfish fragments.
Yellow cat.............	" "	1	11	
Pike..................	" "	6	12½–14¼	Small perch, 3 darters, 1 least darter.
Blue-gill................	May 3.	1	4¼	40 midge larvæ, 4 caddice worms.
Large-mouthed black bass.	" "	1	5¼	Empty.
Pike..................	" "	2	9, 14	Small perch in one, other had nothing.
Rock bass..............	" "	5	4½–8⅜	(a) 2 dragon-fly larvæ and 2 May-fly larvæ. (b) 2 dragon-fly larvae and 2 May-fly larvæ. (c) Parts of 8 small crayfish. (d) A crayfish 2½ inches long. (e) Hexagenia larvæ, a leech, and 4 small crayfish.
Blue-gill................	May 7.	1	8	Miscellaneous insect material.
Large-mouthed black bass.	" "	2	13½, 14	A small crayfish in one, also one in the other.
Pike..................	" "	1	14¼	Empty.
Blue-gill................	" "	3	3½–7	In one stomach 60 midge pupæ and some larvæ.
Long-eared Sunfish.......	" "	1	7¼	A few midges and other insects.
Common sunfish.........	May 9.	3	6–6¼	(a) May-fly larvæ, 2 leeches. (b) Dragon-fly larvæ and 2 caddice worms. (c) May-fly larvæ.
Common sunfish.........	May 9.	4	5½–7	May-fly larvæ and a leech in two, another with nothing, and a fourth with some very small crayfish.
Large-mouthed black bass.	May 9.	1	8½	A leech.

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* Taken with trammel net.

*Table 8.—Data relating to fish taken at station 200.**

Name of fish.	Date.	No. taken.	Length of fish, inches.	Food.
Perch	May 14.	100		
Common sucker	Aug. 6.	13	16 to 19	3 feeding on midge larvæ; 1 had a mass of Daphnia in the alimentary canal.
Whitefish	Aug. 6.	3	14–17½	Stomach filled with Daphnia.
Common sucker	....	2	16½	One empty and the other full of Daphnia.
Whitefish	Aug. 17.	1	14½	Full of Daphnia.
Wall-eyed pike	....	1	2 feet	Small fish.
Common sucker	Aug. 18	12	16, 17	Midge larvæ, many Daphnia.
Whitefish	....	5	12–17	Midge larvæ, many Daphnia.

* All but perch taken in gill net.

*Table 9.—Data relating to fish taken at station 225.**

Name of fish.	Date.	No. taken.	Length of fish, inches.	Food.
Whitefish	April 18.	2	16, 17	200 or more midge larvæ; 90 % of the food in stomachs.
Whitefish	May 5.	3	16–17	Midge larvæ.
Whitefish	May 9.	2	14–18½	Midge larvæ.
Common sucker	May 11.	1	....	3 dozen dragon-fly larvæ; pupæ of same fly.
Whitefish	May 12.	1	....	3 small mussels, some marl and undeterminable material; no midges.
Common sucker	May 14.	3	17	
Whitefish	....	2	16,17	(a) A midge pupæ, 85 midge larvæ, 10 Savomvia. (b) 60 midge larvæ, 3 Sayomyia, a bone of some fish.
Whitefish	May 15.	2	....	Empty.
Whitefish	About the middle of June.	1	....	Midge larvæ, a lot of fish bones and pieces of fish, probably from the bait on the line.

* Taken in gill net except last whitefish, which was caught on set line.

APPENDIX III.

NOTES ON THE AQUATIC INSECTS OF WALNUT LAKE

WITH ESPECIAL REFERENCE TO A FEW SPECIES OF CONSIDERABLE IMPORTANCE AS FISH FOOD.

By JAMES G. NEEDHAM.

In June Prof. Reighard wrote me that the Survey at Walnut Lake was finding insects an important element in the food of fishes there, and asked whether I could not come myself or send some one to study them. Having no one to send at the time, and being greatly interested in the matter because of former similar findings of my own, I determined to go myself, if only for a little while. I was then on the point of departure for the meeting of the American Association for the Advancement of Science at Ithaca, and I stopped off *en route* to spend part of three days at Walnut Lake going, and a week, returning from the meeting. Of these ten days—June 26–8, and July 8–14, I was favored by accessibility of quarters to collecting grounds, by good weather and good equipment, and especially by the intelligent aid of the two men in charge of the station work, Mr. T. L. Hankinson and Mr. Elmer McDonald. But even with these advantages, and with the aid of additional collections made before my arrival and after my departure, it was manifestly impossible to do more than scratch the surface of the insect problem in a few spots. Aquatic insects are a great host, and there is none of them whose life history is not beset with many unsolved problems.

Both Director Lane and Professor Reighard recognized the limitations and merely asked that I should proceed with such collecting and observations as would be possible during my stay. The results are embodied in the following pages.

In company with Mr. C. C. Adams and the station staff I first visited all the collecting stations on the lake, looking out for the most favorable places for finding insects. Then I made a hasty examination of insects collected by Mr. Hankinson from fish stomachs, to see which appeared to be the important species. These proved to be, as usual, midges and May-flies, whose larvæ live in water of some depth.

The activities of the adults begin after sundown: so, at the lake, until dark or later, I spent every evening at the exceedingly difficult task of observing the swarming and mating habits, and succeeded in filling a few gaps in our knowledge of the more important species. I collected by day with a dredge in deep water, or with nets along shore. A single trap lantern, run every night, supplemented the collections with tens of thousands of specimens and a goodly number of additional species, mostly aquatic insects. I made a single trip down the outlet of the lake and found in the rapid part of the stream a fine station for collecting Parnid beetles.

A few species of great importance as fish food, however, received the greater share of my attention, and my observations thereon comprise the first part of the following paper, the second part being an annotated list of the aquatic insects observed, and the third part some observations made in cooperation with Mr. McDonald on a dipterous gall upon the submerged petioles of the yellow water lily.

I. THE IMPORTANT FOOD SPECIES.

Professor Hankinson's detailed report on the food of the fishes of Walnut Lake, given elsewhere in these pages, demonstrates again the great importance of the larvæ of midges of the genus Chironomus and of Mayflies of the genus Hexagenia, and shows that fishes which forage on rocky shores, feed to some extent also upon the larvæ of Mayflies of the genus Heptagenia. These insects have several common characteristics. They all have a very short period of adult life, during which no food is eaten: the mouth parts in all are rudimentary. The adult life of all is concerned solely with reproduction, and they all leave the water with the sexual products practically mature. They all transform in open water, leaving their cast off skins floating upon the surface, and fly to some shelter on shore. They are all nocturnal or crepuscular in their adult habits, and in consequence, are very difficult of observation.

Chironomus.

This great genus of midges is represented by a considerable number of species at Walnut Lake. A few of the larger species that live in the deeper water are doubtless of most importance as fish food: for it is the larger larvæ that are found in their stomachs. The largest species of the genus, *Chironomus plumosus*, was common, and, finding there my first opportunity for making observations on the habits of this species, I gave to it the greater share of my attention and time. I give a special account of it below, following this with some general observation on the structure and habits of a number of others of the larger members of the genus.

It may be said of the larvæ of the larger species of Chironomus that they are the well known "blood worms," one lifts with a dip net out of the black bottom mud of any deep pool, an inch or less in length, cylindric, of a bright transparent red color, legless, save for a pair of short prolegs at each end of the body, the anterior ones ending in a disheveled brush of soft hairs, the posterior ones bearing slender double-arched claws, hairless save for two conspieious tufts of bristles on the end of the last segment of the body above and a few microscopic hairs about the head, living in thin-walled tubes of homespun silk covered with adherent silt, and when torn from their tube swimming with figure-of-eight-shaped loopings of the body, they are easily recognizable by any one.

Chironomus plumosus, Linn. *The Plumed Midge.*—This species is easily recognized by its great size (11 to 12 mm. in length of body); it is the largest of the genus. It is common at Walnut Lake, but would not be likely to be found so except by a collector specially looking for it. An occasional specimen may be seen flying across the water from its place of transformation to find shelter among the trees on shore. Near the water's edge one will occasionally be flushed from a tree trunk or from an overhanging bough, and on sweeping the shore vegetation in sedgy areas with an insect net, one will often be taken from the dry summit of a typha stem. But few of the adults are discoverable except by watching for their evening flights.

Swarming and mating habits.—*Chironomus plumosus* appears on the wing for its mating flight at a time about midway between sundown and dark. Unfortunately, before its appearance nightfall has covered the surrounding woods and meadows with blackness against which the midges cannot be seen at all; they are only visible against the background of the lighted sky above. Hence one cannot see them coming from their resting places to join the company in flight. How eagerly I watched for this, only to have the curtain of darkness fall to the edge of the horizon before any of the plumed midges had been sighted. Then a few would appear overhead, three or four or five of them, eight or ten meters high, and would quickly fall to flying horizontally back and forth upon a regular beat. Gradually they would be joined by others; but they never form thick clouds, as do many of the smaller species. The individuals stand well apart in their flight, with usually several decimeters space between them. After a little while one could determine by changing his base of observation that a considerable area was overhung by the hovering midges.

Their habit is to fly swiftly forward head to wind for a distance of about 10 meters, and then holding the body to the same position still, to drift rather more slowly backward to the starting point. This is repeated continuously by all the individuals in the flight, though not quite synchronously. When a good breeze is blowing they move quite horizontally, and in straight lines; when it is calm their movements are a little less regular. There seems always to be enough movement of the air to determine their position in flight, which is always head to windward. Even at the height of 10 meters one could see by looking carefully that nearly all the individuals were males. An occasional female could be recognized by her distinctly larger size. With a little practice the females could be followed through the entire course of their brief mating flight; for while the males appear to hover with the swarm through the whole period of observation, each female flies but a few minutes. She could be seen entering the swarm, rising in flight as if coming from some resting place in the marshes. She would take her place in the company, falling into step, so to speak, and moving back and forth at a proper interval, in straight horizontal lines. Then, while in her windward course, a male would be seen to approach, to grasp her from above with his feet, and the two would appear as one for an instant. Then, having seized her abdomen with his claspers he would turn about face just at the time when she reached the windward end of the beat, and, heading the opposite way, after the manner of midges in copulation, in apparently active flight, lead the return course to the leeward end of the beat. There they would separate, the male returning to the swarm, the female leaving for parts unknown. She was always lost from view almost immediately. I could only see that in departing her flight had no relation to the wind; she flew obliquely downward, usually in the direction of the lake, but once or twice apparently in the opposite direction toward the trees. The whole mating act occupied hardly more than one or two seconds of time.

The laying of the eggs I did not succeed in observing. The triangle dredge brought up from the bottom a single clump of Chironomus eggs in 30 feet of water, forming so large a mass it could hardly have been laid by any other of our species. It was taken July 9th at station 5, placed in bottle of water in the laboratory, and there the eggs hatched on the 11th and 12th. The young larvæ swam freely upward and outward to become aggregated upon the lighted side of the bottle. Each still carried a little mass of unabsorbed yolk. Doubtless this is the time of their distribution over the bottom. Doubtless this is the time they get into the plankton in greatest numbers; the plankton chironomids are usually minute ones. By the 13 of July about half of those larvæ that had hatched were constructing such sort of cases on the bottom of the bottle and on the paper label it contained as the scanty sediment in the bottle allowed.

The further life history of this species has not been traced. Dr. Johannsen has described larvæ and pupæ from the Renwick marshes at Ithaca, N. Y.

which he has referred to this species with a high degree of probability. The larvæ I found by dredging in 100 ft. of water in Walnut Lake were not the same species described by Dr. Johannsen; neither were those obtained earlier in the season from whitefish stomachs; neither were these last the same as those I dredged. It is highly probable, however, that this is one of several deep-water species of Walnut Lake, for in addition to the occasional very large pupa skins found floating on the surface, Mr. Hankinson has taken the newly emerged imagos on the surface over deep water.

I was able to determine approximately the number of eggs produced by this species by capturing a newly emerged female, keeping her until mature, dissecting out the ovaries and counting the eggs. The newly emerged adult is still reddish in color, especially at the sutures between body segments, the red color of the blood still showing through the slowly darkening cuticle. The ovaries contained in this case about 3000 eggs.

Chironomus meridionalis Joh.—I observed the swarming and mating habits of this species also on several evenings. At station 1 small swarms could be observed almost anywhere along shore as darkness was falling. The swarms maintained an elevation of but one to two meters above the ground. The flight of individuals was head to wind always, through a distance of hardly more than a meter, then a drifting backward to the rear of the swarm, forward and backward, in endless repetition, not, however, in straight lines, as in *Chironomus plumosus*, but with much irregular weaving up and down, and with a constant shifting of relative positions in the swarm. The females stay longer in the swarm in this species. I watched one female twenty minutes from her entering and then lost her without seeing the conclusion of her flight. I observed copulation in a number of other instances; it occurs quite as in *Ch. plumosus*, and has the same sequel—the female departs immediately thereafter, and the male returns to the swarm and resumes flying.

Chironomus albistria Walker.—Mr. McDonald found this species living in green petioles of *Nymphæa advena*, and showed them to me on my first visit to Walnut Lake. I was greatly interested to know a species with such a habit, and suggested that he rear some of the larvæ. This he did, obtaining his first imagos on July 10th. The adults were not observed at large, and nothing is known of their habits. Larvæ and pupæ are described below.

Formerly I found at the campus pond in Lake Forest, Ill., the dead leaves of typha teeming with larvæ of the chironomid *Tanypus carneus*, and I innocently supposed they were eating the leaves, until I made an examination of their stomach contents. This revealed to me the fact that their diet within the leaves was practically the same as that of other chironomid larvæ living upon the pond bottom—diatoms and the minuter algæ—while the tissue of typha were not eaten at all; this was shredded and used to cover the silken tubes within which the larvæ dwelt in the excavations in the leaves, much as others live upon the pond bottom.

The larvæ of *Chironomus albistria* live in elongated excavations in the green nymphæa petioles, having one or more blackish minute openings to the outside. These openings, being slightly discolored, were an easy means of recognizing infested stems. The earliest of the leaves that reach the surface of the water were the ones most infested, and the longest internal chambers, with the largest external openings leading into them, were found near the base of these. However, many of the tunnels were cut high up on young vigorous petioles, and looked as if made by the chironomus larvæ themselves from the beginning; so I was curious to see whether these larvæ were eating green plant tissue. I examined the stomach contents of half a dozen larvæ of different sizes, freshly brought in from the field. In the smaller ones I found only algæ and silt. In all of the larger ones I found a little, and in one of the largest, much, nymphæa tissue. Certain parts of this tissue are exceptionally easy to recognize—the internal hairs, for instance, which spring from junction cells in walls separating the normal air spaces of the tissue of the petiole, and project into those spaces; these hairs are covered with microscopic prickles, and are easily recognizable even in fragments, while whole hairs were frequently found, and in the case of the one larva that had eaten most freely of the tissue, whole junction cells fairly well isolated from their surroundings, and bur-like with groups of these hairs projecting in all directions from them, were present.

The larvæ entering the nymphæa tissue needs but remove a few thin partition walls in order to have space enough to live in. It spins about itself the usual thin tissue of silk, and for a covering uses the materials of the demolished air-space partitions. Over the outside of the older parts of its case, and in the vestibule of its chambers diatoms and other very minute algæ flourish abundantly, as they do all over the outside of the stems. And the manner of life of these larvæ is not greatly different from that of their congeners on the pond bottom. Doubtless they are more protected during larval life; they show also some modifications of the minuter structures of the feeding organs to be mentioned in the following descriptions.

The larva when fully grown measures 16 mm. in length and 1 mm. in diameter. It is of the usual cylindric form, of a bright transparent red color, with a reddish brown head. The two caudal tufts contain each six very close set yellowish hairs, and there are two isolated hairs below the tufts above the anal gills. The latter are four as usual, thick, obtuse and hardly longer than the anal prolegs; there are no other abdominal gills. The claws of the prolegs are obliquely U-shaped. The labial border (Fig. 19) is of a very unusual form, being elongate and deeply bilobed, with no very distinct teeth save the two very large ones that terminate its lobes, and that are separated by a triangular space of their own width. There are faint indications of two low teeth nearer the median line, and of five outside on each lateral margin. The epipharyngeal comb is poorly developed, consisting of a row of three obtuse, triangular tubercles (Fig 19 m).

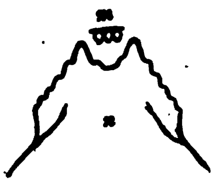

Fig. 19.—*Chironomus albistria* Walker. m—The epipharyngeal comb of the larva; n—the labial border; both x 55.

The pupa measures 12 mm. in length. It is red in color, darkening with age with the appearance of the adult pigmentation. It possesses the usual thoracic tufts of respiratory filaments, sessile, short, spreading and very finely divided by successive branchings. Across the apex of the 2nd abdominal segment on the dorsal side there is a fine line of minute chitinous black teeth, which scarcely extends down upon the sides. The postero-lateral expansion of the 8th abdominal segment ends in a digitate comb of about five posteriorly directed teeth, of which the middle one is longest and strongest, the second and fourth shorter and sub-equal, and the first and fifth minute or rudimentary, and before these on the lateral margin of the segment is a row of four slender distant spinules. The bifid ventral appendage of the end of the abdomen is slightly longer than the body of the caudal fin; the fringe of the fin is semi-circular in outline and continuous over the two lobes; it is composed of very fine silky yellowish hairs, and is one-half longer than the 9th segment.

REMARKS ON TWO OTHER CHIRONOMUS LARVÆ FOUND IN DEEP WATER IN WALNUT LAKE, AND ON THE MEANS OF DISTINGUISHING THE SPECIES.

I have had for study two species of Chironomus larvæ from Walnut Lake obtained from deep water, one taken by myself with a triangle dredge in 100 feet of water, and examined both fresh and preserved; the other taken from the stomach of a whitefish by Mr. Hankinson. The former is apparently identical with the species I found making up the greater part of the food of the brook trout in Bone Pond near Saranac Inn in the Adirondacks in 1900 (figured in detail by Dr. Johannsen on pl. 49 of Bull. 68, N. Y. State Museum). What the species is, is not yet known. Likewise, it is not yet known to what species of adult the other larvæ which the whitefish were eating so extensively in April belongs. It is doubtless a smaller species; the larva lacks blood gills on the penultimate abdominal segment. It is quite like the larva of *Ch. fulviventris* as described in Bull. 86, N. Y. State Museum and figured in plate 22, Figs. 19 and 24–26; but it differs from that species in at least two characters of the sort that usually distinguish species in this genus. (1) The teeth of the labial border are similar as far out from the middle as the third in these two species, but of the remainder each side, it is the seventh (Fig. 20*q*), and not the fourth that is prolonged beyond the level of the tips of the others. (2) The three pieces of the epipharyngeal comb are three-toothed in fulviventris; they are five-rayed in the Walnut lake species (Fig. 20*p* .

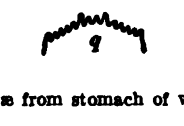

Fig. 20.—Unknown Chironomus larvæ from stomach of whitefish; p—epipharyngeal comb, x 310; q— labial border, x 55.

It should be obvious at once that the most immediate and insistent need of such studies as that in progress at Walnut Lake is further life history work upon these important species. In order to assist any one who may take up that work in the discrimination of species among the larvæ of the genus, I present herewith a semi-diagrammatized figure (Fig. 21) of the mouth parts of the larva of *Chironomus viridicollis*, a species which I have bred from a sluggish stream (the Skokie), near lake Forest and I designate in that figure the typical parts of the curious and complicated mouth apparatus in this genus. It will be observed in the living larva that the mandibles do not oppose each other in the usual way, but instead swing obliquely downward against the toothed edge of the labial border; that the epipharynx and the whole ventral border of the labrum and roof of the mouth has developed an armature of combs and rakers directed backward toward the mouth opening; and that the front of the head is developed into a narrow, rounded prominence, beset with hairs, the lowermost of which are often decurved and pectinated. The homologies of all these parts are by no means clear as yet. The more important parts are designated by tentative and provisional names in the explanation to the figure. The shape, number and proportions of the teeth in the labial border and in the epipharyngeal comb have been found most useful hitherto in the discrimination of the species, and figure 21 and the excellent plates in the monograph by Johannsen will abundantly illustrate the sort of differences likely to be found between them.

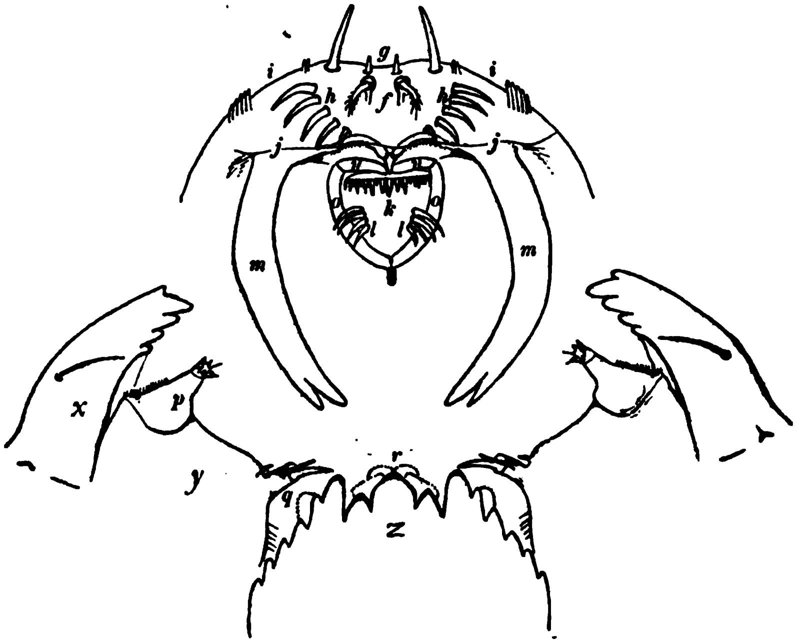

Fig. 21.—Semi-diagrammatic figure of the buccal apparatus of the larva of *Chironomus viridicollis* V. d. W., viewed from below, the mandibles, *x*, and maxillæ, *y*, spread out laterally, and the top of the mouth moved a little anteriorly so as to show all of the epipharyngeal armature (based on drawings by Mr. H. R. Stewart). The line *j-j* represents the labral margin of the mouth; the parts above it are on the front of the head, outside the mouth; the parts below it are in the roof of the mouth. The ill defined fringe of fine bristles along this margin has sometimes been designated as the anterior comb. *f*, the pedunculate palps (only their peduncles are shown in Miall and Hammond's *The Harlequin Fly* Fig 16), *g*, frontal sensory hairs; *h*, *h*, labral or external rakers; *i*, *i*, lateral papillæ; *k*, epipharyngeal (or posterior) comb; *l*, *l*, epipharyngeal or internal rakers; *m*, *m*, lateral arms; *n*, *n*, anterior cross bar; *o*, *o*, U-bar; *p*, maxillary palpus; *q*, lacinia of the maxilla; *r*, hypopharynx?; *z*, the labial border, heavily chitinized (in situ, the mandibles swing obliquely downward against this border).

A simple mode of manipulation enables one to mount preparations of the heads of chironomus larvæ for the microscope to show the above designated parts. The heads are cut off and boiled for a few minutes in a weak solution of caustic potash, then mounted ventral side up in balsam after the usual methods. A slight pressure upon the cover will usually cause the mandibles to swing outward, exposing fully the more important structures. The parts may, of course be dissociated with needles and placed in any desired position.

The larval cases of Chironomus.—As already stated for *Ch. plumosus*, the larva begins a day or two after hatching to construct a case to dwell in. The basis of construction is the more or less silk-like secretion of the remarkable salivary glands, which hardens on contact with the water. It is spun out not in threads, but in tenuous sheets of more or less flocculence, to which silt adheres readily, protectively coloring the whole exterior. Since the larva crawls into the bottom silt and fashions its case there, it is probable that there is no voluntary adding of pieces to the outside as with caddis fly larvæ, but that the secretion holds fast automatically to whatever touches it. That it holds silt securely is evidenced by the figure in plate 75, which was made from cases taken up in a dredge in 100 feet of water, sifted roughly, carried to the laboratory, and lifted out with a forceps on to a white plate before being photographed. These are not portable cases, they are mere run ways or silk-lined tunnels through the silt. They are usually open at both ends, and may readily be torn open anywhere. They are usually many times as long as the larvæ that live in them. The same diatoms and other algæ are found adhering to them and to the bottom silt generally as are found in the larval stomachs. The cases are very fragile, many will not stand to be lifted out of the water by one end. They are not eaten with the larva but are winnowed out. Such sweeping or fanning action of the fins as results from the labor that many fishes perform in the making of their nests would be more than sufficient to tear up the cases and dislodge the contained larvæ.

Fishes eat, and doubtless by preference, the larger larvæ. Some indirect evidence on this point was obtained by comparing the sizes of a lot that had been eaten with a sample catch taken from the lake bottom with the dredge. A short haul was made in 100 feet of water and about half a bushel of black bottom mud was brought up and sifted for Chironomus larvæ. These were separated by Mr. McDonald according to sizes into four groups and counted with the following results:

Length of larvæ.	Number.	%
12–18 mm.	6	1.25
9–10 mm.	75	15.
8–9 mm.	225	46.
7–8 mm.	185	37.75
	491	100

Then a well preserved lot of larvæ from the stomach of a whitefish (No. 680*) were likewise similarly separated into groups and counted, with the following results:

Length of larvæ.	Number.	%
12–18 mm.	99	57
8–12 mm.	70	40
7–8 mm.	5	3
	174	100

Clearly the fishes eat the larger larvæ.

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*This fish had eaten also 5 Sayomyia larvæ, 1 Hexagenia larva and a little mussel, Pisidium.

Hexagenia variabilis Eaton.—This species is common at Walnut Lake, though little in evidence by day. An occasional specimen can be seen flying upon transformation from open water to the woods on shore. At rest on shore, they are conspicuous enough because of their large size. They sit rigidly, and, if approached quietly, allow themselves to be picked up with the fingers. I could not discover any place or time of swarming, nor find any considerable number of individuals on the wing at any given place. Yet the abundance of the cast skins that float upon the surface shows that a considerable number of imagos are emerging all the while. In Bull. 47, N. Y. State Museum, I published an account of the life history of this species with figures of larval and adult stages.

The eggs are probably laid upon the surface of the water, the female falling flat upon the water with wings outspread and liberating them there. I frequently saw females floating thus at nightfall, but was not able to demonstrate that they were ovipositing. Many other Mayflies liberate their eggs in this manner. The eggs doubtless settle to the bottom, tending apart as they fall, and becoming scattered somewhat, according to the depth and currents of the water. The larvæ live as shallow burrowers in the bottom silt. The length of the larval life is unknown. When grown they swim to the surface and transform there. The subimago emerges suddenly from a rent in the back of the old larval skin, its wings expanding fully almost at once; it stands for an instant on the surface and then flies away toward the shore. This transformation occurs at any time of the day or night. The final moult, the casting of the subimago skin occurs within 24 hours thereafter, the period intervening being spent in inactivity. The evening following is probably the period of adult activity—the time when the mating flight occurs, and when the eggs are laid, though observations are yet lacking upon these points.

I was able to determine at Walnut Lake the egg-laying capacity of this species. I captured sub-imagos when leaving the water or when resting on shore, kept them through their final moult until fully adult and obtained their eggs. I was preparing to get the eggs by dissection of my first specimen when I made a curious discovery. I placed the fully adult female upon water in a watch-glass and with fine scissors, snipped off her head. Immediately she began depositing her eggs* in the water beneath her, pouring them out rapidly from both oviducts, and not ceasing until they were all deposited (this I determined by dissection later). This occupied not more than two minutes. A partial count and estimate of the number of eggs thus laid put it at about 9000. The method thus found being so easy of application, I repeated the performance with a number of other females, obtaining somewhat smaller numbers, though the lowest estimate was 7850 eggs. The average number was about 8000.

The eggs are translucent whitish, oblong, broadly rounded on the ends, and show no visible micropyle. They are already filled at laying with minute yolk balls. The chorion is very thin and transparent, and the gelatinous envelope is exceedingly scanty, and at first little adhesive, insomuch that the eggs roll freely about in the water. However, after they have lain in the water a few hours a gelatinous connection is easily seen between two eggs that lie in contact, and any silt in the water becomes attached to them. These eggs being unfertilized, showed no signs of further development.

It was most interesting to see this automatic response on the part of the female to an unusual stimulus, leading to the complete performance of the last important act of her life. I doubt not that it may be brought about in other ways. Mr. Viereck showed me a pair of this species that he had caught somewhere in Pennsylvania on his way to the Ithaca meeting. Having no cyanide bottle he killed them by pinching the thorax, whereupon the female extruded *into the air* in two oblong packets the entire contents of her ovaries.

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* This reaction does not follow like treatment of any other Mayfly on which I have tried it—not even the closely allied *H. bilineata* Say.

Along the wave-washed, marl-floored shallows between stations 1 and 7, and between stations 7 and 15 I could find any evening a number of adult females flying. They were certainly "going through the motions" of laying eggs, falling flat upon the surface with wings outspread, rising, flying on, and falling again, or sweeping along for a time close to the jutting edge of the sedge zone at the shore. But I caught a dozen or more of them at different times and they were all spent females, with no eggs remaining. This, always just as darkness was closing in. They had laid their eggs probably earlier in the evening, and perhaps farther out from shore. The larvæ are found mainly in deeper water.

Heptagenia pulchella and the *twilight procession of swarming species.*—This is in every respect a very different May-fly, more nocturnal, more secretive, more fragile, with depressed larvæ that cling closely to stones, preferably on wave-washed shores. The larvæ are eaten by shore-feeding fishes, and are easily collected by picking them from stones quickly lifted out of the water, but the imagos are infrequently seen. Subimagos, at leaving the water fly to lights occasionally; they transform within twenty-four hours and probably mate and oviposit the night following their last moulting, though this has not yet been observed.

There is a regular procession of crepuscular insects appearing on the wing for their mating flight on the shore of Walnut Lake during July. Directly after sundown the little red-eyed fly, *Synechis simplex* Walker, appears in ill defined companies darting about in irregular, though chiefly horizontal flight, usually near, but not over the water. Then the beautiful May-fly, *Ephemera simulans*, appears in companies of males over the edge of the water. The flight of one of these companies is a most delightful performance to witness, it is so light and graceful, and appears, withal, so exhilerating. Yet it is all up and down in vertical lines. With upturned head each individual flies rapidly upward, mounting quickly to a height of ten or fifteen meters, then spreading its wings out horizontally it falls upon them, with long fore legs extended forward and longer tails extended backward full length, rudderlike, keeping it always head to wind. Thus it descends floating on the air, yet not drifting, until, at the lower level of the swarm (four or five meters above the water), it lifts its head and rises rapidly again in flight. And the whole company flying and falling thus, weaving up and down in vertical lines, and passing and repassing each other, create a scene of great animation.

About as soon as the flight of the *Ephemera* swarms is well established, *Chironomus plumosus* appears in the horizontal flight that I have described on preceding pages. *Chironomus meridionalis* also appears nearer the ground. Then, as the darkness deepens, the May-fly *Cœnis*, the smallest of all the *Ephemera*, comes out to perform in little swarms, which one may see if he chance to come close enough; they are hardly visible for a distance of more than a few feet. These are males also, which weave up and down in straight lines hardly rising higher than one's head.

Last of all the visible performers, *Heptagenia*, appears when it is almost too dark to see, in small companies of males, which weave up and down *obliquely*, flying forward and upward, head to wind, and drifting and settling downward and backward to the starting point. How high these go could hardly be told on the several occasions when I watched them, the white forms being little visible against the sky (one could see them but a few feet) but they descend to a level easily within reach of a net. Whether females come near these swarms when in search of mates I was wholly unable to observe. Detailed knowledge of the mating and ovipositing habits of this species will be gleaned with great difficulty. A search light which we brought into requisition at station 1 was of no practical assistance in observing any of the flights above described.

I reared this species at Saranac Inn, N. Y., in 1900, and published a description of the larvæ in Bull. 47, N. Y. State Museum, p. 421 (Pl. 15, Fig. 15). The importance of the larvæ as fish food may be gathered from the facts Mr. Hankinson has furnished elsewhere in this report. The food of the larvæ consists of such dead plant materials, and living algæ intermixed therewith as they may find about the under surfaces of the stones to which they cling. It is intermixed with much silt and with some sand. I examined a number of specimens carefully and could find no animal remains whatever.

II.—ANNOTATED LIST OF THE SPECIES OBSERVED.

Plecoptera. Stoneflies.

1. *Chloroperla brunneipennis* Walsh. Two males of this species came to a trap lantern set by the aquaria on the outlet of Walnut Lake on the night of July 1st. They were the only stoneflies seen.

Ephemerida. Mayflies.

1. *Ephemera varians* Walsh.—Swarming flights (described above) of thispecies I observed off stations 1 and 15. The species was apparently coms mon earlier in the season, for it would have been hard to get during my stay so many specimens as Professor Hankinson took on the 29th of May at station 46. The larvæ were taken at a number of stations on the softer marl bottoms. Their food consists of marl and the substances intermixed therewith. It is readily dissected out of the alimentary canal as a cylinder of apparently pure marl, which when crushed on a cover glass reveals scanty amounts of remains of filamentous algæ, and of the disintegrating fragments of the higher plants from shore. I could discover in it no animal remains whatever.

2. *Hexagenia variabiliis* Eaton.—I took adults of this species on every day of my stay at Walnut Lake. Mr. Hankinson took a subimago in transformation on the 25th of June. His fish food data will show the wide seasonal and dietary range of the species. I have already given an account of its habits so far as known.

3. *Heptagenia pulchella* Walsh.—Probably occurs at all the stations where there are stones or timbers to which the larvæ can cling. They are easily collected in abundance at station 23. While we were coursing round with a searchlight in the bow of the boat at station 54 a number of subimagos, apparently just risen from the water, came to the light. I have given above brief and fragmentary notes on the habits of the species.

4. *Callibœtis ferruginea* Walsh.—Of this species I collected at station 7 a few males, swarming just before dark, weaving up and down in a small

company, and a single female, swept from a clump of Decadon near by—July 7th. Although I did some collecting hereabout, I did not find the larva.

5. *Blasturus cupidus* Say.—Two female subimagos of this species were found floating on the surface at station 225 on the 14th of May., probably having drifted out with the wind from shore; this is not characteristically a deep-water form.

6. *Ephemerella excrucians* Walsh.—A few larvæ of this species were collected at stations 6, 26 and 28 during the month of May.

7. *Ephemerella* sp.—A single curious larva *with prominent head tubercles,* was taken on the 26 of May (Coll. No. 927).

8. *Cœnis diminuta* Say.—Imagos and subimagos of this species came to our trap lantern at station 1 in some numbers on the nights of 7th, 9th, and 13th of July. I observed the males swarming in their flights at stations 1 and 7. I took a few larvæ in a triangle dredge at station 4, and in a sieve net at station 7. The larvæ are so small and cling so closely to the stems, even when withdrawn from the water that they are not often seen.

Odonata. Dragonflies and Damselflies.

1. *Gomphus spicatus* Hagen.—This species was flying not uncommonly when I first arrived at the lake on June 26, and a few specimens were captured when they alighted on the boat that day and the day following. I found young larvæ abundant at station 1, and sifted out quite a number of them from the bottom marl with a sieve net. There were taken from most of the shore stations at different times during the season. The cast nymphal skins were found associated with those of the following species, which see.

2. *Dromogomphus spinosus* Selys.—This species was coursing the surface of the lake with the foregoing one late in June, and would alight once in a while on the boat, where two specimens were captured. I found the cast nymphs skins at station 27, where there is a narrow beach of sand, some three feet wide, with stunted sedge growth at its landward side. They lay at the rear of the sand, among the projecting sedge roots, and were hard to find, though not uncommon. The bottom slopes rapidly here, and is silted with marl and strewn with coarse gravel. Bottom collecting on such a shore should find the larvæ.

3. *Basiæschana janata* Say.—A single cast larval skin of this species was found clinging to a stem that overhung the outlet brook about 100 yards distant from the lake.

4. *Aeschna clepsydra* Say.—Occasional adults of this species were seen coursing the lake during July. One male captured served for identification. A few large nymphs of the genus that may as well as not be of this species were collected during May.

5. *Anax junius* Drury.—This ubiquitous species, so common to the southward, was at Walnut Lake rather rare. I saw but one or two specimens flying. I captured a single nymph at station 7.

6. *Macromia illinoiensis* Walsh.—This fine species is very common about the chara beds on the bottom of the lake, especially where the growth is sparse, exposing flat bottom areas on which the larvæ may lie hidden. There are few finer examples of protective coloration than these larvæ present, nevertheless, they are much eaten by fishes. If overturned by the fishes in fanning the bottom, they would be readily seen with the light yellow color of the under surface of the body exposed. I took larvæ with the triangle

dredge at station 4 and in the deeper water opposite; also with a sieve net at station 1, and they have been taken in many other places in the lake, always in connection with a scanty growth of chara. Mr. McDonald found larval skins of this and the next following species on the sedges at the bank at station 34. No adults were observed.

7. *Epicordulia princeps* Hagen.—This species was constantly seen in flight over the lake. None were captured, however. Being easily recognizable in flight, it was not deemed desirable to make the effort necessary to catch even a single specimen. The copius masses of gelatinous egg strings seen commonly about the borders of the lake hung upon projecting stems just below the surface of the water, doubtless belonged either to this or to the species next following. I took larvæ of this species at stations 1 and 7, and Mr. McDonald took cast skins from shore at station 34 as noted above.

8. *Tetragoneuria cynosura* Say.—This species was rather common, one or two specimens were taken on my first visit for the sake of certain determination. I found the larvæ abundant at station 7 and they were collected sparingly at other places. Doubtless some of the egg masses referred to above belonged to this species. I have figured these in Bull 47, N. Y. State Museum, p. 491.

9. *Somatochlora* sp.—Several young larvæ that I took with sieve net at station 7 are nearest this genus, but are not like those of any of the known larvæ described therein.

10. *Perithemis domitia* Drury.—I saw a single male of this species sitting on a nymphæa leaf at station 54, and though I did not capture it, I was close enough for certain identification.

11. *Celithemis elisa* Hagen.—This beautiful insect was very common all about the lake. During sunshine the adults were flying in pairs all about the bulrush beds, while the solitary males exercised "squatter sovereignty" over little areas, perched on the top of some tall stem standing in the midst of his domain. During the first week of July the cast larval skins were hanging thickly to the bulrush stems. I collected the nymphs at station 7.

12. *Celithemis eponina* Drury.—I took a single larva of this species at station 7, and I think I saw one or more of the adults in flight.

13. *Leucorhinia intacta* Hagen.—Common, especially about the nymphæa beds. I collected the larvæ at station 7.

14. *Sympetrum rubicundulum* Say.—This species was just becoming common on the wing at the time of my departure. That was too early for many *Sympetra*. Doubtless other species would be found later in the season.

15. *Pachydiplax longipennis* Burmeister.—A few specimens of this species were seen in June, and one was captured. The larva apparently was not encountered.

16. *Mesothemis simplicicollis* Say.—I captured a single adult of this species July 14, by the outlet to Evans' pond, near Walnut Lake. Mr. Hankinson took two larvæ at Orchard Lake on the 18th of June.

17. *Ladona exusta* Say.—I captured a single adult of this species at station 20 on June 26.

18. *Libellula luctuosa* Burmeister (= *basalis* Say).—Not uncommon about the shallows bordering the lake; belongs to the fauna of pools and shallow ponds rather than to that of lakes.

19. *Libellula pulchella* Drury.—This is an abundant species of some importance to fishes that feed in shallow water. In all collecting with hand nets from the bottom it was encountered. It was abundant at stations 1 and 7. In such places the females could frequently be seen ovipositing

by dipping the tip of the abdomen repeatedly and rapidly into the surface of the water.

20. *Tramea lacerata* Hagen.—Two adults of this species, apparently, were seen but not taken. No larvæ of this genus were encountered.

21. *Calopteryx maculata* Beauvois.—This species swarmed about the outlet, more abundantly in the rapid places in the stream, where many females could be seen busily depositing their eggs in the trailing and hardly submerged stems of *Potamogeton nuttalli*.

22. *Lestes unguiculata* Hagen; 23. *Lestes rectangularis* Say.—These two species were both found among the vegetation on the west shore of the lake —single male specimens of each.

24. *Lestes vigilax* Hagen. 25. *Lestes inequalis* Walsh.—These two species were found on the outlet a hundred yards distant from the lake—single male specimens of each.

26. *Argia violacea* Hagen.—Common all around the lake and down the outlet; more characteristic of flowing than of still water.

27. *Nehallennia irene* Hagen.—Abundant about the outlet. Could be swept in the sedge zone about the lake almost anywhere.

28. *Enallagma hageni* Selys; 29. *Enallagma ebrium* Hagen; 30. *Enallagma civile* Hagen.—All found about the lake border, the first most common, the last least common. Transforming in the bulrushes everywhere, but no attempt was made to identify the larvæ.

31. *Enallagma antennatum* Say.—Very common about the outlet.

32. *Enallagma signatum* Hagen; 33. *Enallagma pollutum* Hagen.—Both very common, especially about stations 15 and 54. The latter is the latest flying of all Odonata, pairs being seen on the wing repeatedly when it was too dark to tell without capturing them in a net and looking more closely, whether they were big Mayflies (*Hexagenia*) or not.

34. *Ischnura verticalis* Say.—Rather uncommon; taken only a few times.

Hemiptera.

The following species of this order were kindly determined by Mr. J. R. de la Torre Bueno of New York City:

Corisa sp.—Young individuals not uncommon about submerged vegetation.

Notonecta variabilis Fieb.—Common at station 7.

Ranatra quadridentata Stal.—Adults were rarely seen, but half grown larvæ were common at many places in shore vegetation. A few floating typha stems bristling with the curious appendages of the contained ranatra eggs were found at station 7.

Belostoma (formerly *Zaitha*) sp.—A few adults were taken with a sieve net from the ditch back of station 7.

Gelastocoris sp.—This undescribed species was common on the narrow strip of sandy beach at station 27.

Acanthia sp.—Not uncommon on mud at edge of water.

Gerris marginatus Say; *Gerris sp.* (undescribed).—Common everywhere on the water at the edge of the standing vegetation.

Neuroptera.

Sialis infumata Say.—This orl fly was very abundant at Walnut Lake early in the season. Larvæ were collected on the bottom in many places during April and May, and they were then being eaten commonly by fishes.

About the latter end of May the adults were abundant ; those in the collection bear the date of May 23rd. I took off station 3, in thirty feet of water, a half-grown larva of the next season's brood.

Chauliodes rastricornis Say.—A few young larvæ, probably of this species were found singly crawling on the under surfaces of nymphæa leaves.

TRICHOPTERA. Caddis flies.

Determined by Dr. C. Betten.

Phryganeidæ.

1. *Neuronia semifasciata* Say.—One female was collected on May 31st (No. 936) and another came to a lighted window of the laboratory on July 7th.

2. *Neuronia concatenata* Walker.—A number of specimens came to the window with the preceding species July 7th; two others, undated, bear the collection number 1383.

Limnophilidæ.

3. *Platycentropus hostis* Hagen.—One male (No. 1383).

4. Larvæ of an undetermined *Limnophiline*, in cases of vegetable matter covered with small bits of mussel shells and stones (the larger 33 mm. long) were taken, 4 on April 6th, and 4 on April 7th (Nos. 25 and 30).

5. Another *Limnophiline* larva, in a case ballasted after the manner of the case of Goera, was taken on the 10th of July.

Sericostomatidæ.

6. *Heliocpsyche* sp.—Several larvæ were taken from stones in a riffle in the outlet of Walnut Lake (the location for Parnid beetles mentioned elsewhere) on July 10th, and a single adult was swept from the sedges on the adjacent bank.

7. *Lepidostoma* sp.—One male, July 12th.

Hydroptilidæ.

8. *Agraylea* sp.—Trap lanterns drew a few female specimens during July.

9. *Oxyethira* sp.—A single female captured on the 25th of June bears the number 1313.

10. *Hydroptila* sp.—Four larvæ and one pupa in parchment cases 6 mm. long by 1½mm. wide, were taken from Nymphæa petioles July 12th.

11. *Hydroptilid* larva of undetermined genus, in parchment cases 4 mm. long by 1 mm. wide at the one end tapering to ½ mm. wide at the other, taken with the preceding species, and attached like the cases of that one to the erect nymphæa petioles by two hold fasts at each end. These were obtained while collecting the stem-infesting *Chironomus* and *Hydromyza* larvæ, and were very common; they might have been obtained in great numbers.

A large number of additional adult *Hydroptilidæ* were obtained by the trap lantern on the nights of the 25th of June and the 7th, 12th and 13th of July, but being mostly females, preserved in alcohol, they are hardly identifiable.

Hydropsychidæ.

12–23. Four species of the genus *Hydropsyche* came to the trap lantern on the 25th and 26th of June, and 12th and 13th of July; nearly all females.

Likewise, 3 species of the genus *Plectrocnemia*, and two of *Holocentropus*, one of each of these latter being very common. A species of *Tinodes* is likewise represented in the lantern catch of the same date by a number of females. Several larvæ of *Chimarrha*, and of one other undetermined *Hydropsychid* were taken from the rocks in the outlet of the lake on July 10th.

Leptoceridæ.

24. *Molanna cinerea* Hagen.—This species swarmed around a search light that was carried in the prow of the boat at station 54 on the night of July 13th, and a few were taken. A few additional came to the trap lantern.

25. *Triænodes ignita* Walker.—This species came commonly to the trap lantern, a few on the 25th of June and on the 7th of July, and many on the 13th.

26–35.—Four species each of *Oecetis* and *Leptocerus*, one *Leptocella* and one *Setodes*, came also to the trap lanterns with the foregoing on the 25th of June and the 7th to the 13th of July. A few of these represented in some numbers by both sexes, will doubtless later be more specifically determinable.

At least 35 species are represented in the collection, nearly all obtained in the trap lantern on four favorable evenings. The material was not adequately cared for, being merely dumped into alcohol; it is sufficient, however, to indicate that there is a good caddisfly fauna in Walnut Lake to reward the more careful labors of the future collector.

Coleoptera.

Haliplus ruficollis, DeG.—Three adult specimens I took with a seive from the trash in the ditch back of station 7 on July 11th. Though especially sought for, not a single *Dytiscid* was seen.

Gyrinidæ were not very common, but could be found in the more sheltered places among shore vegetation.

Gyrinid larvæ were taken not infrequently. I took a small one at station 1, and a larger one in deeper water at Station 7. A large one taken by Mr. McDonald at station 47, and put in a vial of water to be brought home alive with some larvæ of *Chironomus albistria*, was of a beautiful transparent red color when I received it, half an hour later; but three of the midge larvæ had become white; the color was transferred with their blood.

A single adult *Tropisternus* was taken on June 26th.

A number of small larvæ of *Hydrophilidæ* were taken with a seive net in the ditch back of station 7.

A few specimens of *Berosus* sp. came to a trap lantern set beside the aquaria on the outlet the night of July 12th.

Macronychus glabratus Say.—Abundant on stones in the rapids a mile from the lake—the station for the following Parnidæ also.

Stenelmis sp.—Likewise abundant.

Elmis bivittatus Lec.—One specimen taken.

Elmis quadrinotatus Say—Common.

Ancyronyx variegatus.—One specimen taken.

Galerucella nymphæa—Common about the nymphæa beds, the larvæ feeding in considerable numbers on the leaves.

Donacia palmata—Common about nymphæa beds.

Donacia. sp.—Less common, about the Scirpus covered areas.

DIPTERA.

Tipulidæ. Craneflies.

Goniomyia subcinerea O. S.; *Goniomyia blanda*, O. S.—Came commonly to light, the former in greater numbers.

Limnobia cinctipes Say—Under linden trees on shore; rarely attracted to light.

Amalopis inconstans O. S.—In deep shade on shore; rarely attracted to light.

Erioptera chlorophylla, O. S.—One of the commonest *Tipulidæ* at Walnut Lake, if not the commonest. It could be found by sweeping vegetation anywhere near shore. Taken in the trap lantern every night, and often in considerable numbers.

Antocha opalizans, O. S.; *Erioptera straminea*, O. S.; *Erioptera caloptera*, Say; *Erioptera parva*, O. S.; *Erioptera septentrionis*, O. S.; *Geranomyia canadensis*, Westw.; *Ulomorpha pilosella*, O. S.; *Limnophila quadrata*, O. S.; *Rhamphidia flavipes*, Macq.—All came to light; all could be collected by sweeping under the edges of the tree growth on shore.

Bittacomorpha clavipes.—A ditch back of the Decadon beds at station 26. The north inlet to the lake sheltered this species in abundance.

Tipula sp. Common throughout the sedge zone.

Toxorrhina magna O. S.—A single female specimen taken from a boat as it flew overhead at station 15 just before dark on July 8th.

CULICIDÆ. Mosquitos.

Psorophora ciliata Fabr.—A few specimens only of this species came to the trap lanterns.

Anopheles punctipennis Say.—Common; many taken in trap lantern.

Anopheles maculipennis Meigen.—Not common; but few seen.

Culex perturbans.—The predominant mosquito, whose biting was not uncommonly bad.

Sayomyia punctipennis Say.—Abundant; taken by thousands in the trap lantern when set with out-look over the lake. Larvæ perhaps of this species were eaten by whitefish.

CHIRONOMIDÆ. Midges.

The species named below have been determined by Dr. O. A. Johannsen of Cornell University:

Rhyphidæ.

Rhyphus punctatus (trap).
Chironomus plumosus, Linn.
Tanypus monilis (some in trap) numerous.
Tanypus sinuosa.
Protenthes culiciformis.
Procladius pusillus (trap).
Chironomus meridionalis (numerous).
Chironomus tentans.
Chironomus albistria (bred).
Chironomus similis (numerous).
Chironomus scalaenus var. (trap).

Chironomus pallidus (trap).
Chironomus devinctus (trap).
Chironomus brunneipennis (trap).
Chironomus halteralis (trap) numerous.
Chironomus decorus.
Chironomus plumosus
Chironomus nigricans
Chironomus viridicollis.
Cricotopus trifasciatus (some in trap) numerous.
Cricotopus sylvestris.
Metriocnemus exagitans (trap).
Tanytarsus flavellus (trap).

Tabanidæ.

These and the following families have been determined by Mr. D. W. Coquillett of Washington, D. C.:

Tabanus lineola Fabr.; *Chrysops striatus* O. S.; *Chrysops plangeus* Wied.; *Chrysops niger* Macq.—All common along shore.

Stratiomyiidæ.

Odontomyia vertebrata Say; *Odontomyia plebeja* Loew.—Occasionally seen flitting over vegetation about the shores. Egg masses were rather common on projecting bur-reed leaves.

Leptidæ.

Chrysopila proxima Walker.—Common at the outlet.

Scatophyagidæ.

Hydromyza confluens Loew.—This species, which makes galls in the petioles of nymphæa leaves is especially discussed further on.

Empididæ.

Syneches simplex Walker.—This is the species that leads the procession of swarming species after sundown, as detailed in preceding pages.

Cyrtidæ.

Ogcodes costatus Loew.—On willow tree overhanging water at outlet.

Syrphidæ.

Eristatis bastardi Macq.—Over shallow water about aquatic plants everywhere.

Eristalis flavipes Walker; *Eristalis transversus* Wied.—Common about the shores.

Helophilus conostonus Will.—Common on iris flowers in the edge of the outlet.

Ephydridæ.

Hydrillia hypoleuca Loew.—Swarming upon white water lilies, blackening the flowers within by their abundance.

III.—AN AQUATIC GALL ON THE YELLOW WATER LILY, *Nymphœa advena.*

While collecting the larvæ of the midge *Chironomus albistria* Walker, from their holes in the petioles of nymphæa Mr. McDonald and I frequently came upon galls associated with them in the stems. These galls appear to be the first made known upon a member of the water lily family (Nymphæaceæ); also the first known to be made by a member of the dipterous family Scatophagidæ; also the first to be found deeply and constantly submerged. Therefore a brief account of them should not be without interest.

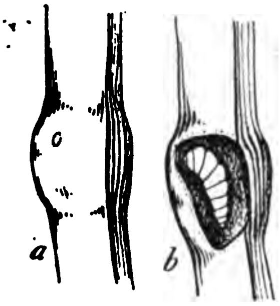


Fig. 22.—Gall-bearing petioles of *Nymphœa advena*. *a*, external views of the gall; the dotted circle marks the epidermal window, through which the adult emerges. *b*, the gall cut open, showing the larva of *Hydromyza confluens* within.

The galls are rounded swellings upon the petiole, distending it and increasing it by a fifth to a third its normal diameter (Fig. 22). They may occur anywhere, except close to the surface or close to the bottom of the water. They are placed singly along the petiole, but occasionally are close enough together to appear superficially confluent. They occur most frequently upon the stalks of the earliest of the leaves that reach the surface (not at all upon the short stalked and wholly submerged leaves of earliest spring), and very sparingly upon the later leaves. On a vigorous plant with eleven floating leaves and two flower stalks, examined at station 26 on July 12th, nine pupæ and three larvæ were found in the petiole of the oldest leaf, while three were found in the two petioles next younger. Probably the attack of the gall maker begins when the first leaves reach the surface in late spring; then they have their first opportunity to reach the proper place of oviposition by crawling down the stalk.

The insect that causes the gall to grow is the larva of the fly *Hydromyza confluens* Loew (family *Scatophagidœ*). No observations were possible upon any stages except the later larval, and pupal, and the transformation to the adult. The cavity within the gall is rather close fitting until the larva is well grown, but becomes larger and its walls become discolored later. Just before transformation to the pupal stage the larva eats a hole out to the epidermis, and returns to the center of the cavity; this hole is a passage of exit for the adult, which then has only to break through the transparent epidermal window to gain its liberty.

The grown larva measures 9 mm. in length and 2 mm. in greatest diameter; it is shorter and thicker when contracted. The body is of a somewhat fusiform outline, rather obtuse at each end, gradually thickened to the fourth or fifth segment, and then slowly tapered posteriorly. The color is white.

No head is visible, but only a blackish mouth at the front end, below. A perforate cribriform plate of an inconspicuous brown color at each side of the prothoracic segment close behind the mouth terminates the longitudinal tracheal trunk of each side; this is shown at *d* in Fig. 6, dissected out entire. The air trunks end posteriorly in three pairs of radially placed slits, the lower one of which has its margin prolonged in a stout triangular sharply pointed spine. This spine is shown at the end of the body in Figure 6a; it is shown in side view enlarged more at Figure 6b; and the end view of spiracular aperatures of both air trunks are shown in their relative positions at Figure 6c. The form and position of this spine suggest that it may be used to break open the walls of air spaces in the nymphæa tissues, as a correspondingly placed spine connected with the spiracle in the larva of the beetle *Donacia* is used to puncture the tissues from the outside.

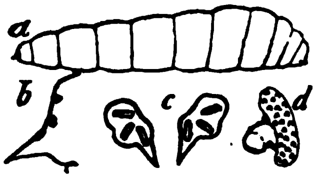


Fig. 23.—The larva of *Hydromysa confluens*. *a*, side view of the whole larva; *b*, the caudal peritreme spine, greatly enlarged; *c*, posterior view of the respiratory aperatures; *d*, the prothoracic spiracular apparatus, removed and enlarged (the mark close behind the mouth in the upper figure shows the location of this.)

At transformation, the larval skin contracts into a puparium, the anterior spiracular apparatus becomes pushed out upon each side to form a prominence as high as wide, and the perforations appear as minute roughness upon its surface; the posterior spines remain projecting; the contracted body within shapes itself into the pupa, and between this and the anterior end of the puparium is clearly seen through the transparent wall the furcated buccal armature that lined the larval mouth.

The decaying of the tissues about the walls of the gall when the leaf gets old, together with the perforation of the wall by a passage for exit, weaken the stalks, and they break readily across the top of the gall during the pupal stage of the contained insect. Thus the pupae are readily obtained. Some of those obtained on the 12th of July were placed alive in a dry bottle, and several of these transformed the next day. About the same time adults were noticed commonly about the lily beds, sitting upon the leaves, and taking flight readily upon approach. On the night of July 13th, while we were boating with a search light about station 54, they flew in some numbers to the light. This species will doubtless be found commonly about Nymphæa beds in the United States, notwithstanding that it appears to have been reported hitherto only from Canada.

INDEX.

35

INDEX.

A.

Page

Abyssal region of Walnut Lake ... 239
Acanthia sp. ... 265
Acknowledgments, Walnut Lake work ... 162
Actitis macularia ... 237
Adams, A. A., map of Walnut Lake ... 163
    C. C., Walnut Lake work ... 161, 162, 252
Aeschna clepsydra ... 263
Agelaius phoeniceus ... 237
Agraylea sp ... 266
Alaska, Malaspina glacier, forests of ... 170
Algae ... 219, 220, 226, 228, 237, 249, 255, 256
Amalopsis inconstans ... 268
Ambloplites rupestris ... 210
Ameiurus natalis ... 208
    nebulosus ... 208
American bittern ... 237
    coot ... 237
    crow ... 237
    toad ... 235
Amia calva ... 199
Amnicola limosa ... 192, 235
    lustrica ... 235
Ampelis cedrorum ... 237
Amphibians ... 235
Amphipods ... 178, 180, 188, 207, 213, 233, 245, 249
Anabœna ... 228
Anax junius ... 263
Ancyronyx variegatus ... 267
Anemometer ... 243
Aneroid barometers ... 243
Annelid worms ... 232
Anodonta grandis footiana ... 235
Anopheles maculipennis ... 268
Anopheles punctipennis ... 268
Antocha opalizans ... 268
Antrim shale, Oakland county ... 165
Aphanothece stagnina ... 228
Apparatus, description of ... 240
Aquaria ... 243
Aquatic and marsh plants, effects of on habitat ... 222
Aquatic gall ... 270
    weeds ... 252
Arbor vitae ... 220
Arcella ... 232, 249
Ardea herodius ... 237
Ardetta exilis ... 237
Argia violacea ... 265
Argyrosomus artedi ... 199
Aromochelys odoratus ... 236

Page
Artificial introduction, black bass.... 213

B.

Bach, Ellen, Characeae.... 162, 229
Back swimmers.... 188, 234
Banks, Nathan, spiders.... 162
Barn swallows.... 191, 237
Barograph.... 243
Barred killifish.... 178, 179, 182, 188, 189, 192, 199, 209, 239, 250
Barren shoal type, field stations.... 174, 175
  summary.... 181
Barrows, W. B., reference.... 162
Bascanion constrictor.... 236
Basicœschana janata.... 263
Basswood.... 228
Batrachium divaricatum.... 231
Batrachospermum boryanum.... 228
Beasley Lake, oxygen.... 196
Bed rock, Walnut Lake.... 165
Beach.... 228
Beetles.... 183, 188, 192, 205, 209, 212, 234, 252, 271
Belostoma.... 265
Belted kingfisher.... 237
Berosus sp.... 267
Betten, C.... 266
Birds.... 237
Birge, E. A., Daphnea.... 162
  oxygen of Wisconsin lakes.... 196–198
  thermometers.... 243
Bittacomorpha clavipes.... 268
Bittern, American.... 237
Black ash.... 227
Black bass.... 176, 178, 180, 181, 183–186, 188–192, 199, 200, 204, 208, 213, 215, 230, 233, 239, 246, 247, 249, 250
Black-chinned minnows.... 179, 188, 189, 191, 192, 199, 202, 206, 239
Black-crowned night heron.... 237
Black oak zone.... 220, 228
Black spruce.... 220
Blackbird.... 188, 191, 192, 237
Bladderwort.... 225, 226
Blanding turtle.... 188, 236
Blasturus cupidus.... 263
Blue-gill.... 176, 180–183, 184, 186, 188–191, 199, 212, 213, 234, 245–247, 249, 250
Blue-green sunfish.... 186, 199
Blue racer.... 236
Blue-spotted sunfish.... 163, 184, 188, 189, 199, 210, 230, 234, 247, 249, 250
Blunt-nosed minnow.... 176, 178–181, 183, 184, 186–189, 191, 192, 199, 202, 204, 205, 212, 216, 239
Boat.... 240
Botaurus lentiginosus.... 237
Boleosoma nigrum.... 215
Bottom material, barren shoal type.... 182
Bow fin.... 199
Bower, S., Michigan Fish Commission.... 240
Brama chrysoleucas.... 205
Brass, J. L., Michigan Fish Commission.... 240
Breeding habits, fishes.... 201, 205–208, 210–216
Briggs, T. H., reference.... 162
Broad leaved cattail.... 229
Brook silversides.... 199
Brook stickleback.... 199, 210
Brook trout.... 257
Bufo americanus.... 235
Bugs.... 234
Bullhead.... 181, 184, 188–191, 192, 199, 204, 208, 246, 247, 249, 250
Bulrush.... 219, 220, 223–227, 230

Page
Bulrush-covered shoal type, field stations ... 174, 182
  summary ... 185
Bulrush shoal type, field stations ... 174, 190
Bur oak ... 228
Bur-reed ... 229
Butorides virescens ... 237

C.

Caddice-flies ... 188, 234, 266, 267
Caddice worms ... 180, 207, 212, 213, 245–247, 249, 250
Caldwell, O. W., reference ... 162
Calico bass ... 199
Calkins, G. N., Protozoa ... 162
Callibœtis ferruginea ... 262
Calopteryx maculata ... 265
Cambarus bartoni robustus ... 233
  diogenes ... 233
  propinquus ... 233
Cameras ... 244
Carbon dioxide, water of Walnut Lake ... 195
Castalia tuberosa ... 230
Catfish ... 208
Catostomidae family ... 207
Catostomus commersonii ... 207
Cattail flag ... 223–226, 229
Cayuga minnow ... 179, 180, 182, 188, 189, 192, 199, 202, 205, 239
Celithemis elisa ... 264
  eponina ... 264
Centrachidae family ... 210
Ceratophyllum demersum ... 230
Ceryle alcyon ... 237
Chaetomorpha chelonum ... 228
Chara contraria ... 229
  fragilis ... 229
Characeae ... 171, 220, 229
Chase, Dr. H. H., diatoms ... 229
Chauloides rastricornis ... 266
Chelydra serpentina ... 236
Chimarrha ... 267
Chironomidae ... 268
Chironomus ... 195, 198, 234, 253, 255, 266
  albistria ... 255, 267, 268, 270
  brunneipennis ... 269
  decorus ... 269
  devinctus ... 269
  fulviventris ... 257
  larvae ... 257, 259
  meridionalis ... 255, 261, 268
  nigricans ... 269
  niveipennis ... 234
  pallidus ... 269
  plumosus ... 253, 255, 259, 261, 268, 269
  scalaenus var ... 268
  similis ... 268
  tentans ... 268
  viridicollis ... 257, 258, 269
Chloroperla brunneipennis ... 262
Chœtomorpha chelonum ... 228
Chrysemys marginata ... 236
Chrysopila proxima ... 269
Chrysops niger ... 269
  plangeus ... 269
  striatus ... 269
Chub-sucker ... 182, 187, 188, 191, 192, 199, 207
Coccoei scutellum ... 229
Cœnis ... 261
  diminuta ... 263

Page
Coldwater shale, Oakland county........ 165
Coleoptera........ 267
Collecting........ 240
Colletonema lacustre........ 229
Collins, F. S., algae........ 162, 228
Colorimeter........ 243
Condition of fish........ 199
Conferva bombycina........ 228
Coniferous trees........ 220, 227
Coot, American........ 237
Copepods........ 215, 249
Coregonus clupeiformis........ 200
Corethra larvæ........ 193, 200, 234
Corisa sp........ 265
Corvus brachyrynchos........ 237
Cottidae family........ 216
Cottus ictalops, miller's thumb........ 216
Cranefiles........ 268
Crawford, Frank, whitefish........ 200
Crayfish........ 179, 180, 182, 185, 188, 200, 208, 210–215, 233, 246, 247, 249, 250
Crickets........ 212
Cricotopus sylvestris........ 269
  trifasciatus........ 260
Crow........ 237
Crustaceans........ 233
Culex perturbans........ 268
Culicidae........ 268
Cyanophyceae, depositing agent of bog lime........ 171
Cyclorella meneghiniana........ 229
Cymbella gastroides........ 229
Cyprinidae family........ 202
Cyrtidae........ 269

D.

Damsel-flies........ 183, 188, 191, 192, 214, 233, 263
Daphnia........ 193, 195, 198, 201, 207, 233, 245, 251
Darwin, C., insectivorous plants........ 231
Davis, C. A., peat........ 185
  report on flora........ 217, 237
  Walnut Lake plants........ 161, 162, 229, 237
Decodon........ 263
  verticillata........ 231
Deep water type, field stations........ 174, 192
Description, Walnut Lake........ 164
Desmids........ 205
Detroit, crayfish........ 233
Diatoms........ 194, 229, 255
Dichotomosiphon tuberosus........ 228
Difflugia........ 232
Dina fervida........ 233
Dip net........ 241
Dipper, Walker........ 242
Diptera........ 234, 268
Donacia........ 192, 267, 271
  palmata........ 267
Drag seins........ 240, 247, 248
Dragon-fly........ 180, 183, 185, 188, 191, 192, 210–212, 233, 245–247, 249–251, 263
Draparnaldia plumosa........ 228
Drayton Plains, bass hatchery........ 240
Dredges........ 241
Dromogomphus spinosus........ 263
Duck-weed........ 224, 227, 230
Dytiscid........ 267

E.

Eastwood, John, water analyses........ 161, 195
Eel-grass pond-weed........ 230

Page
Eggs, aquatic insects 253-255, 260, 261, 264
Elkhart Lake, oxygen 196
Elmis bivittatus 267
    quadrinotatus 267
Empididoe 269
Emydoidea blandingi 236
Enallagma antennatum 265
    civile 265
    ebrium 265
    hageni 265
    pollutum 265
    signatum 265
Entomostraca 194, 201, 205–207, 212, 215, 233, 249, 250
Ephemera simulans 261
    varians 262
Ephemerella excrucians 263
    sp 262
Ephemerida 263
Ephydridoe 269
Epicordulia princeps 264
Equipment for work 162
Equisetum sp 229
Erimyzon sucetta oblongus 207
Erioptera caloptera 268
    chlorophylla 268
    parva 268
    septentrionis 268
    straminea 268
Eristalis flavipes 269
    transversus 269
    bastardi 269
Eropdella punctata 232
Esocidae family 209
Esox lucius 209
    vermiculatus 209
Etheostoma iowæ 178–181, 184, 188, 189, 191, 192, 199, 216, 239
Eucalia inconstans 210
Eucrangonyx gracilis 233
Eupomotis gibbosus 213

F.

Fauna of Walnut Lake 232
Faxon, Mr., Cambarus 233
Ferns 219
Fiber zibethicus 238
Field stations 173
Firm shore type, field stations 174
Fish, barren shoal type 182
    list of 200
Fish of Walnut Lake 198
Fish, stomach contents, data on 244
Fishing, methods of 200
Flat worms 232
Flies 234, 261
Floating pond-weed 229
Flora and marl soil 221
Flora of highlands 228
Flora, Walnut Lake district 217
Food, fish 201, 202, 204–215, 233, 245–253, 257, 262
Formaldehyde 244
Fort Wayne moraine 169
Frog 179, 235, 236
Fulica americana 237
Fundulus diaphanus 209
Fyke nets 240, 247

G.

Page

Galerucella nymphoea........ 267
Gall, aquatic, yellow water lily........ 270
Garter snake........ 236
Gas contents........ 195
Gasterosteidae family........ 210
Gavia imber........ 237
Gelastocoris sp........ 265
Geology, Walnut Lake area........ 164
Geranomyia canadensis........ 268
Gerris marginatus........ 265
  sp........ 265
Gill net........240, 247, 251
Glacial geology of Walnut Lake region........ 166
Glochidia sp........ 235
Gloiotrichia natans........ 228
Glossiphonia stagnalis........ 232
Gnat........ 234
Golden shiner........178, 179, 181, 183, 186–189, 191, 192, 199, 202, 205, 232, 239, 249
Gomphonema acuminatum........ 229
Gomphus spicatus........ 263
Goniomyia blanda........ 268
  subcinerea........ 268
Grass pike........182, 200, 209
Grasses........219, 220, 227
Grasshoppers........177, 212, 234
Great blue heron........ 237
Greater bladderwort........ 231
  duckweed........ 230
  yellow-legs........ 237
Green frog........188, 192, 236
  heron........ 237
Grinnell, Henry, whitefish........ 200
Gyrinid........ 267
Gyrinidae........ 267

H.

Habitats, fishes........200, 204–216
Haliplus ruficollis........ 267
Hankinson, T. L., aquatic insects........252, 253, 255 257, 262, 264
Habitat, effects of aquatic and marsh plants on........ 222
Hard maple-beech zone........ 220, 228
Harvey, N. H., fresh water sponges........ 161, 232
Heliocpsyche sp........ 266
Helodromas solitarius........ 237
Helophilus conostonus........ 269
Hemiptera' aquatic........ 234, 265
Heptagenia........212, 213, 233, 246, 247, 249, 253, 261
Heptagenia pulchella........ 261, 262
Heron........ 237
Herring........ 199
Hexagenia 212, 213, 233, 245–250, 253, 265
  variabilis........ 259, 262
Hickories........ 228
Highlands, flora of........ 228
Hirundo erythrogaster........ 237
Hoemopsis marmoratus........ 233
Holocentropus........ 267
Hop, horn beam........ 228
Hornbeam........ 228
Horned dace........188, 199, 202, 205
Hornwort........225, 226, 230
Horse-tails........ 229
Human agencies affecting Walnut Lake........ 171
Hyalella knickerbockii........ 233
Hydrachnids........ 249, 250

Page

Hydrillia hypoleuca 269

Hydromyza 266

  confluens 269, 270

Hydrophilidae 267

Hydropsychid 267

Hydropsychidae 266

Hydroptila sp 266

Hydroptilid larva 266

Hydroptilidae 266

Hyla versicolor 235

Hypnum 226, 229

I.

Illegal fishing 200

Insects 207, 233, 234, 252

Invertebrates, barren shoal type 182

  bulrush-covered shoal type 183

  marsh bay type 188

  swampy shore type 192

Iridoprocne bicolor 237

Ischnura verticalis 265

Ithaca, N. Y., Renwich marshes 254

Ivy-leaved duckweed 230

J.

Johannsen, O. A., aquatic diptera 162, 234, 254, 255, 257, 258, 268

Johnny darter 176, 178–179, 181, 184, 189, 191, 199, 204, 215, 216, 235, 239

Junipers 227

K.

Kildeer 237

Kingfisher 192, 237

L.

Labidesthes sicculus 199

Ladona exusta 264

Lake Arkona 169

Lake Forest, Ill., chironomid larvæ 255, 257

Lake Maumee 169

Lake Mendota, Wis., oxygen 196, 197, 198

Lake trout 198

Lake Whittlesey 169

Lampropeltis doliatus triangulus 236

Lane, A. C., Walnut Lake work 161, 162, 252

Lantern, trap 242

Large-leaved pond-weed 230

Larva, Chironomus albistria 255, 256

Least bittern 237

Least darter 178, 181, 184, 187–189, 192, 199, 216, 239, 250

Leeches 178, 192, 211–213, 215, 232, 246-250

Lemna minor 230

  trisulca 230

Leopard frog 179, 235, 236

Lepidostoma sp 266

Lepornis cyanellus 210

  euryorus 186, 191, 199, 211

  megalotis 212

  pallidus 212

Leptidoe 269

Leptocella 267

Leptoceridae 267

Leptocerus 267

Lesser duckweed 230

Page
Lestes inequalis........ 265
    rectangularis........ 265
    unguiculata........ 265
    vigilax........ 265
Leucorhinia intacta........ 264
Libellula luctuosa........ 264
    pulchella........ 264
Limestones, plants of........ 166
Limnaea desidiosa........ 178, 235
Limnobia cinctipes........ 268
Limnophila quadrata........ 268
Limnophilidae........ 266
Limnophiline........ 266
List of (aquatic) species, annotated........ 262
List of fish, annotated........ 200
List of plants, Walnut Lake........ 228
Littoral region of Walnut Lake........ 238, 239
Location, Walnut Lake........ 164
Long-eared sunfish........184, 191, 199, 211, 212, 250
Loon........ 237

M.

McDonald, Elmer, reference........161, 252, 255, 259, 264, 270
Macrobdella decora........ 233
Macromia illinoiensis........ 263
Macronychus glabratus........ 267
Malaspina glacier, forests of........ 170
Mammals........ 238
Manitou darter........ 199
Maps, Walnut Lake........ 163
Marl, Walnut Lake........170, 221, 225
Marsh bay type, field stations........ 174, 187
    summary........ 189
Marsh wren........188, 191, 192, 237
Marshall gravel, adjacent to Walnut Lake........ 172
Marshall sandstone, Oakland county........ 165
May-fly........ 180, 183, 185, 208–210, 212, 213, 215, 233, 247, 249, 250, 252, 253, 260–262, 265
Measurements........ 163
Melosina varians........ 229
Melospiza georgiana........ 237
Mesothemis simplicicollis........ 264
Method of work........ 162
Metriocnemus exogitans........ 269
Miami gravelly loam, soils of Walnut Lake drainage basin........ 172
    sandy loam, adjacent to Walnut Lake........ 172
Michael, Ellis, Walnut Lake work........ 161, 202
Michigan Fish Commission........198, 200, 214, 240, 241
Microperca punctulata, Least darter........ 216
Micropterus salmoides........ 213
Midges........177–180, 182, 184, 185, 189, 191, 183–195, 201, 204, 205,
    207–210, 212–215, 232, 234, 245–254, 267, 268
Milk snake........ 236
Miller's thumb........176, 178, 182, 199, 204, 216
Minnow seine........ 250
Minnows........178–182, 184, 186–188, 192, 202–204, 209, 210, 212–215, 241
Molanna cinerea........ 267
Mollusks........178, 180, 182, 192, 201, 207, 235, 249, 251
    collecting........ 242
    marl........ 171
Moore, J. P., leeches........ 162, 232
Mosquitos........ 268
Moss........ 226, 229
Mougeotia sp........ 228
Mud minnow........192, 209, 249
Musk turtle........181, 187–189, 191, 236

Page
Muskrat 188, 189, 191, 236, 238
Myriohyllum heterophyllum 231
  spicatum 231

N.

Naias flexilis 230
Natrix fasciatus sipedon 236
Navicula radiosa 229
  acuta 229
Needham, Jas.G., Walnut Lake insects 161, 162, 183, 188, 233, 234, 242, 252
Nehallennia irene 265
Nets 240–242
Neuronia concatenata 266
  semifasciata 266
Neuropterous insects 234, 265
Nitella sp 229
Nitzschia linearis var. tenuis 229
Nomenclature 163
Norway and Jack pine zone 220
Notonecta variabilis 265
Notropis anogenus 189, 199, 202, 206
  blennius 206
  cayuga 205
  cornutus 206
  heterodon 206
  rubrifrons 199
Nycticorax nycticorax naevius 237
Nymphaea advena 230, 255, 270

O.

Observations, recording and making 240, 242
Observing 240
Odonata 263
Odontomyia plebej 269
  vertebrata 269
Oecetis 267
Ogcodes costatus 269
Ophrydium versatile 176, 232
Orchard Lake 199, 206, 264
Ortmann, A. E., crayfish 162, 233
Ostracods 215
Outlet head, field station 174
Oxyechus vociferus 237
Oxyethira sp 266
Oxygen dissolved 195–198, 239

P.

Pachydiplax longipennis 264
Painted turtle 181, 187, 188, 191, 236
Parasites, fish 163
Parnid beetles 252, 266, 267
Peat, Walnut Lake 171, 222
Perca flavescens 214
Perch 176, 178–183, 184, 186–190, 192, 193, 199, 209, 214, 233, 246–251
Percidae family 214
Percina caprodes zebra 199
Perithemis domitia 264
Peters, Joseph, fisherman 161
Philotria canadensis 230
Phryganeidae 266
Physa heterostropha 235
  sp 235
Physiographic features, shores of Walnut Lake 172
Physiography, Walnut Lake area 164
Pickerel 199, 209

Page
Pickerel weed........225, 226, 230
Pied-billed grebe........237
Pieters, A. J., references........242
Pike........179, 181, 184, 188, 189, 191, 199, 209, 248, 250
Pimephales notatus........204
Pisciola punctata........233
Pisidium........192, 235, 259
Placobdella parasitica........232
    rugosa........232
Plankton........196, 198, 233, 242, 254
Planorbis bicarinatus........235
    campanulatus........235
    parvus........192, 235
Plant distribution in a given lake, factors controlling........218
        law governing........218
Plant hooks........242
Plant zones of the lake and bottom soils........220
    represented in Walnut Lake........223
    Walnut Lake, ideal classification........220
Plants, adaptation of........217
Plants and rainfall........220
    barren shoal type........182
    list of........228
    reason for zonal arrangement of........219
    requirements of........217
    water, types of........218
Platycentropus hostis........266
Plecoptera........262
Plectrocnemia........267
Plumed midge........253, 254
Podilymbus podiceps........237
Poeciliidae family........209
Polygonum amphibium........230
Pomoxis sparoides........199
Pond-weed zone, barren shoal type........182, 213, 239
Pond-weeds........210, 220, 225–227, 229, 230, 237
Pontederia cordata........230
Pontiac area, soil map........163
Post-glacial history of Walnut Lake........169
Potamogeton amplifolius........230
    foliosus........237
    heterophyllus........230
    lucens........230
    natans........229
    nutalli........265
    proelongus........230
    pusillus........237
    zosteroefolius........230
Preservation methods........244
Procladius pusillus........268
Protenthes culiciformis........68
Protozoa........232
Protozoan........176, 182
Psorophora ciliata........268
Pupa, Chironomus albistria........256

R.

Rainfall and plant distribution........220
Rana clamitans........236
    pipiens........235
Ranatra quadridentata........265
Recording observations........240, 243
Red-bellied leech........188
Red-eyed fly........261
Red oak........228

Page
Red-winged blackbird....188, 191, 192, 237
Reighard, Jacob, Walnut Lake work....161, 162, 195, 239, 252
Relations of plants to animals.... 217
Renwick marshes, Ithaca, N. Y.... 254
Reptiles.... 236
Richardson, R. E., sunfish and minnows....162, 206, 211, 244
Rhamphidia flavipes.... 268
Rhyphus punctatus.... 268
Rock bass..180, 181, 184, 186, 188, 189, 191, 192, 199, 210, 211, 230, 233, 234, 245, 247, 249, 250
Rosy-faced minnow.... 199
Rotifers.... 194
Round worms.... 232
Rushes.... 224
Russell, I. C., forest of Malaspina glacier.... 170
Ruthven, A. G., amphibians and reptiles.... 162

S.

Salmonidae family.... 200
Sandstones, areas plants of.... 166
Saranac Inn, near, brook trout.... 257, 262
Sartwell's sedge.... 224
Sayomyia.... 251
Sayomyia larvæ....194, 201, 234, 251
punctipipennis.... 268
Scarlet oak zone.... 220, 228
Scatophyagidae.... 269
Schilbeodes gyrinus.... 208
miurus.... 199
Scirpus lacustris.... 230
Scorpions, water.... 234
Scytonema ocellatum.... 228
Searchlight.... 243
Sedge zone, barren shoal type.... 182
Sedges....219, 220, 223, 224, 226, 227
Sericostomatidae.... 266
Seed-plants.... 229
Semotilus atromaculatus.... 205
Set-line.... 241, 251
Setodes.... 267
Shales and plants of.... 166
Shiner, common....186, 199, 202, 206
Shining pond-weed.... 230
Shrub-sphagnum zone.... 220, 227
Shrubs.... 219
Shull, A. Franklin, insects of Walnut Lake.... 161, 233
Sialis....184, 192, 201, 212, 214, 234, 246
infumata.... 265
Sieve net.... 242
Siluridae family.... 208
Simpson Lake, fish.... 199
Slender naias....226, 230, 237
sedge.... 224
Snails....180, 192, 213, 215, 235, 247
Snake.... 236
Snapping turtle.... 181, 236
Soft maple.... 227
Soil map, Pontiac area.... 163
Soil sampler.... 242
Soils, drainage basin of Walnut Lake.... 172
Soils, relation of the zonal distribution of plants.... 221, 222
Solitary sand-piper.... 237
Somatochlora sp.... 264
Sparganium eurycarpum.... 229
Sparrow.... 237
Spearing of fish.... 200

Page

Species of fish, numbers and economic importance ... 199
Sphagnum ... 219
Spiders ... 183, 234
Spike-rush ... 224
Spiked water milfoil ... 231
Spirodela polyrhiza ... 230
Spirogyra ... 228, 249
Sponges ... 232
Spotted sandpiper ... 237
Station 1 ... 207, 216, 261–264
    3, barren shoal type ... 179, 187, 202, 207, 210, 212, 215, 224, 234, 266
    4, bulrush covered shoal type ... 184, 211–213, 216, 225, 230, 232, 263, 264
    6, barren shoal type ... 181, 184, 210, 214, 216, 224, 230, 236, 263
    7, ... 189, 190, 209, 210, 213–216, 225–234, 236–238, 261–265, 267
    12 ... 210, 212, 237
    13 ... 216
    15, bulrush-covered shoal type ... 182, 210–216, 224, 225, 229, 232, 233, 261, 262, 265, 268
    16, barren shoal type ... 180, 212, 216, 224, 226, 236
    19 ... 211, 212, 214
    20 ... 211, 213, 214, 225, 233, 264
    23, barren shoal type ... 175, 204, 212, 215, 223, 225, 228, 229, 235–237, 262
    24 ... 210, 212, 213, 229
    26, swamp loosestrife-fringed type ... 186, 210, 211, 213, 215, 216, 227, 228, 230, 231, 236, 237, 263, 264, 268
    27, aquatic insects ... 263, 265
    28 ... 224, 263
    31, swamp loosestrife-fringed type ... 185, 206, 211, 215, 227, 230, 231, 236
    32, barren shoal type ... 177, 212, 223, 224, 227, 232, 235, 237
    33 ... 228
    34, aquatic insects ... 264
    36 ... 209, 235, 236
    40 ... 209, 213–215, 224, 227–231, 236–238
    41, marsh bay type ... 188, 190, 206, 209, 210, 213, 215, 216, 224, 226, 228–232, 234–236, 238
    42 ... 210
    44 ... 235
    45 ... 206, 215, 232, 233
    46, barren shoal type ... 178, 190, 201, 202, 209, 214, 224, 229, 236, 262
    47 ... 228, 267
    49, barren shoal type ... 178, 190, 201, 215, 216, 235
    51 ... 230
    54 ... 209–215, 225–227, 229–231, 233, 237, 238, 262, 264, 265, 267, 271
    70 ... 236
    200, deep water type ... 193, 194, 214, 215, 229
    225, deep water type ... 193, 194, 207, 241, 263
    250, deep water type ... 194
Stenelmis sp ... 267
Sticklebacks ... 210
Stizostedion vitreum ... 214
Stomach contents, fish, data on ... 244
Stonecat ... 182
Stoneflies ... 262
Stoneworts ... 219, 220, 222, 223, 225–227, 229
Stratiomyiidae ... 269
Straw-colored minnow ... 176, 178, 179, 181, 184, 186, 188, 189, 192, 199, 202, 204, 206, 214, 216, 239
Sucker ... 180, 184, 188, 193, 194, 199, 207, 239, 245, 246, 247, 251
Summary, barren shoal type ... 181
    bulrush-covered shoal type ... 185
    fauna of Walnut Lake ... 238
    marsh bay type ... 189
Sunfish ... 176, 178–181, 183–189, 191, 192, 199, 204, 210–213, 215, 230, 233, 234, 239, 245–249
Surtella ovalis var. angusta ... 229
Swallow ... 237
Swamp forest zone ... 220
Swamp loosestrife ... 223, 224, 227, 231, 236
Swamp loosestrife-fringed type ... 174, 185

Page
Swamp shore type, field station 174, 191
Swamp sparrow 237
Swamp white oak 227
Sympetrum rubicundulum 264
Syneches simplex 261, 269
Synedra ulna, var. lanceolata 229
Syrphidae 269

T.

Tabanidae 269
Tabanus lineola 269
Tadpoles 179, 236
Tadpole stone cat 188, 189, 199, 208, 249
Tamarack 220
Tanypus carneus 255
    monilis 268
    sinuosa 268
Tanytarsus flavellus 269
Telmatodytes palustris 237
Temperatures, water 177, 178, 180, 182–185, 194, 195, 202, 203, 243
Tents 244
Tetragoneuria cynosura 264
Thamnophis sirtalis 236
Thermometers 243
Thermophone 243
Tinodes 267
Tipula sp 268
Tipulidae 268
Toad-bugs 234
Toads 235
Totanus melanoleacus 237
Touch-me-not 227
Toxorrhina magna 268
Tramea lacerata 265
Trammel net 241, 247
Trap lantern 242
Trawl 241
Tree swallow 237
Tree-toad 235
Tree zone, barren shoal type 182
Triangle dredge 241
Trichoptera 266
Trioenodes-ignita 267
Tropisternus 267
Trout Lake, Wisconsin 197, 198
Turbidimeter 243
Turtle 181, 188, 189, 191, 236
Tussock sedges 224
Twig-rush 224
Typha latifolia 229

U.

Ulomorpha pilosella 268
Umbra limi 209
Umbridae family 209
U. S. Bureau of Fisheries 241, 243
U. S. Fish Commission 198
U. S. Geological Survey, map of Walnut Lake and environs 163
Utricularia vulgaris 231

V.

Valvata tricarinata 192, 235
Various-leaved pond weed 230
    water milfoil 231
Vaucheria sp 228, 235
Viereck, Mr., aquatic insects 261

Page

- Vorticella, 183, 232

W.

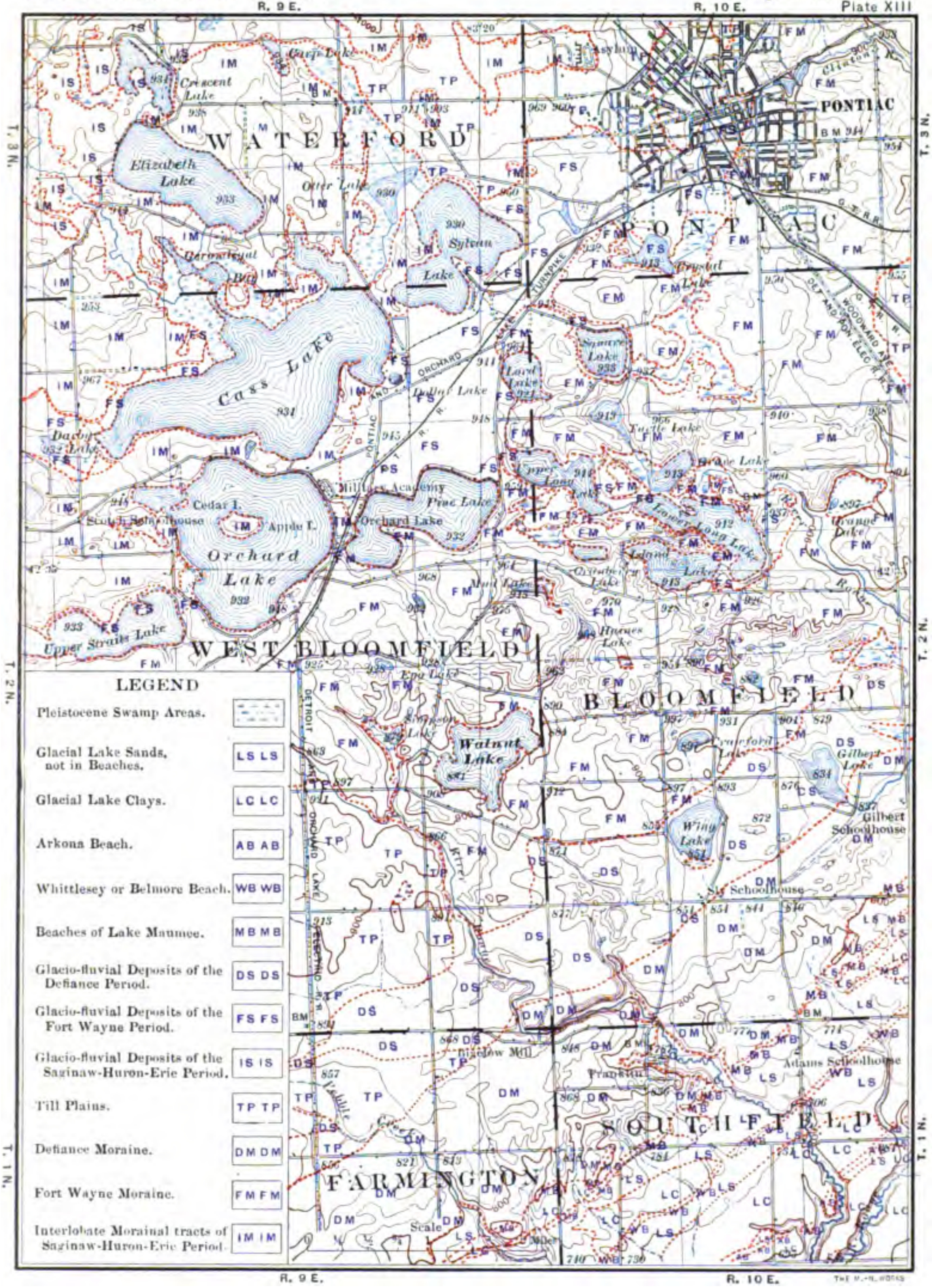
- Walker, Bryant, Mollusks, 161, 162, 235, 242
- Walker dipper, 242
- Wall-eyed pike, 181, 184, 188, 193, 199, 200, 214, 246, 247, 249, 251
- Walnut, 228
- Walnut Lake, fauna of, 232
  - origin of, 169
- Water bug, giant, 234
- Water crowfoot, 226, 227, 231
  - fleas, 209
  - glass, 242
  - lilies, 219, 220, 224–227
  - milfoil, 225, 226, 231, 237
  - mites, 211, 235
  - moss, 249
  - persicaria, 226, 230
  - plants, types of, 218
  - scorpions, 234
  - sedges, 224
  - snake, 236
  - spiders, 188, 234
  - striders, 188, 234
  - supply and plant distribution, 218
  - weed, 226, 230
- Waxwing, 237
- Weckel, Ada, amphipods, 162, 233
- Western painted turtle, 236
- Whipple, G. C., and Parker, H. N., gas contents of water, 195
- White elm, 227
  - oak-hickory zone, 220, 227, 228
  - pine zone, 220
  - stemmed pond-weed, 230
  - water lily, 225–227, 230
- Whitefish, 179, 180, 184, 193-195, 198–200, 204, 207, 232–234, 239, 241, 244, 247, 251, 255, 257, 259
- Williams, Gardner, map of Walnut Lake, 163
- Wisconsin lakes, oxygen, 196
- Worms, 232

Y.

- Yellow catfish, 181, 183, 184, 188, 189, 191, 192, 199, 208, 246, 247, 249, 250
  - oak, 228
  - perch, 180, 181, 191, 214, 245, 247
  - water lily, 225–227, 230, 270

Z.

- Zaitha sp, 188, 234, 265
- Zygnema sp, 228

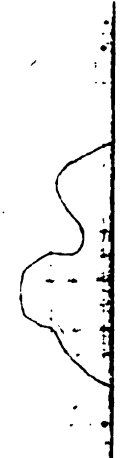

R. 9 E.
R. 10 E.
T. 3 N.
T. 2 N.
T. 1 N.
WATERFORD
PONTIAC
WEST BLOOMFIELD
BLOOMFIELD
SOUTHFIELD
FARMINGTON
Elizabeth Lake
Cass Lake
Orchard Lake
Sylvan Lake
Pine Lake
Walnut Lake
Wing Lake
Gilbert Lake
Upper Straits Lake
Crescent Lake
Otter Lake
Long Lake
Square Lake
Cedar I.
Apple I.
LEGEND
Pleistocene Swamp Areas.
Glacial Lake Sands, not in Beaches. LS LS
Glacial Lake Clays. LC LC
Arkona Beach. AB AB
Whittlesey or Belmore Beach. WB WB
Beaches of Lake Maumee. MB MB
Glacio-fluvial Deposits of the Defiance Period. DS DS
Glacio-fluvial Deposits of the Fort Wayne Period. FS FS
Glacio-fluvial Deposits of the Saginaw-Huron-Erie Period. IS IS
Till Plains. TP TP
Defiance Moraine. DM DM
Fort Wayne Moraine. FM FM
Interlobate Morainal tracts of Saginaw-Huron-Erie Period. IM IM
Scale
R. 9 E.
R. 10 E.

SURFACE GEOLOGY OF THE VICINITY OF WALNUT LAKE

Compiled by Charles A. Davis, from a manuscript map by Frank Leverett, U. S. Geological Survey.

Topographic base by the United States Geological Survey, 1906. Contour interval 20 feet. Datum is mean sea level.

Geological Survey



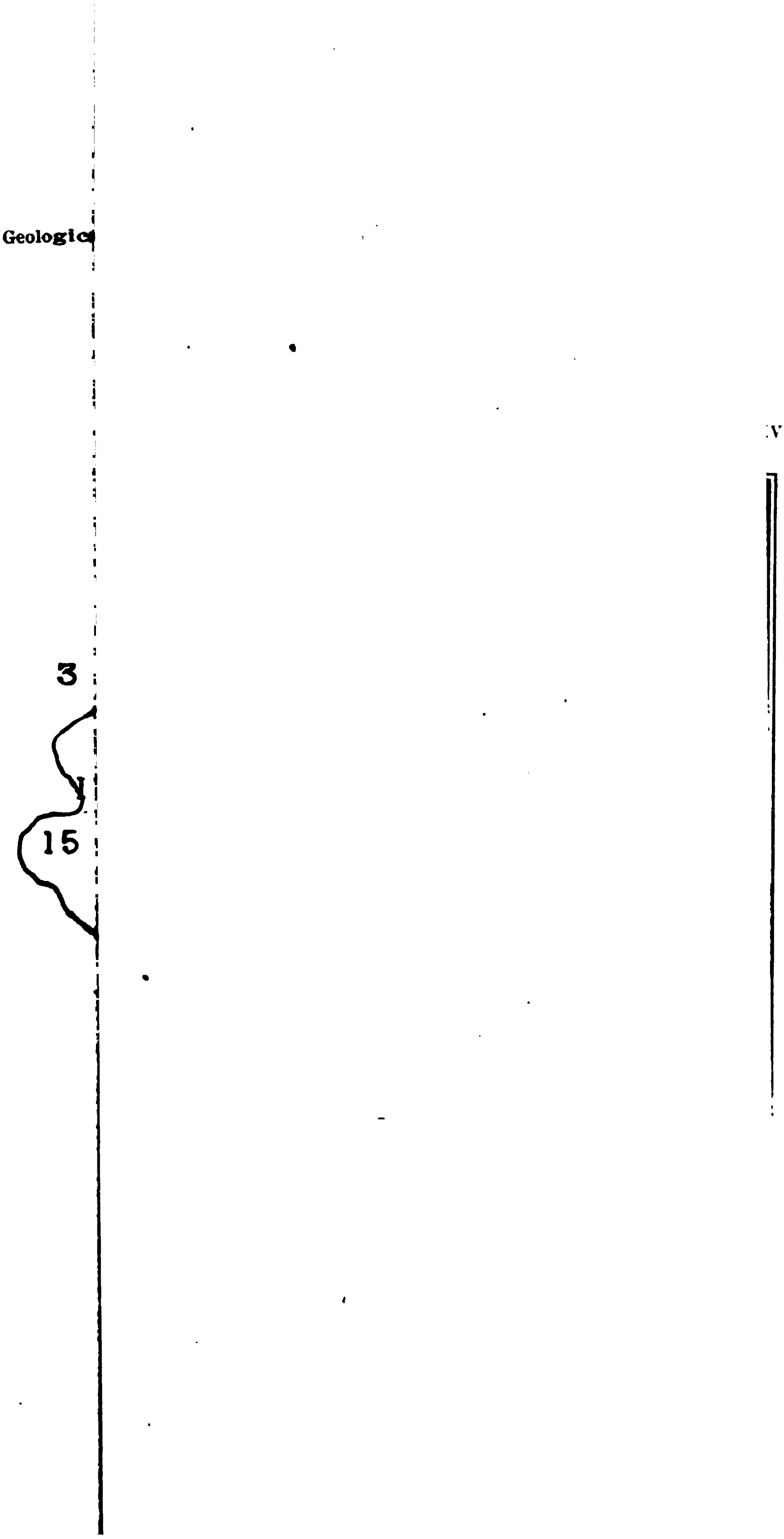

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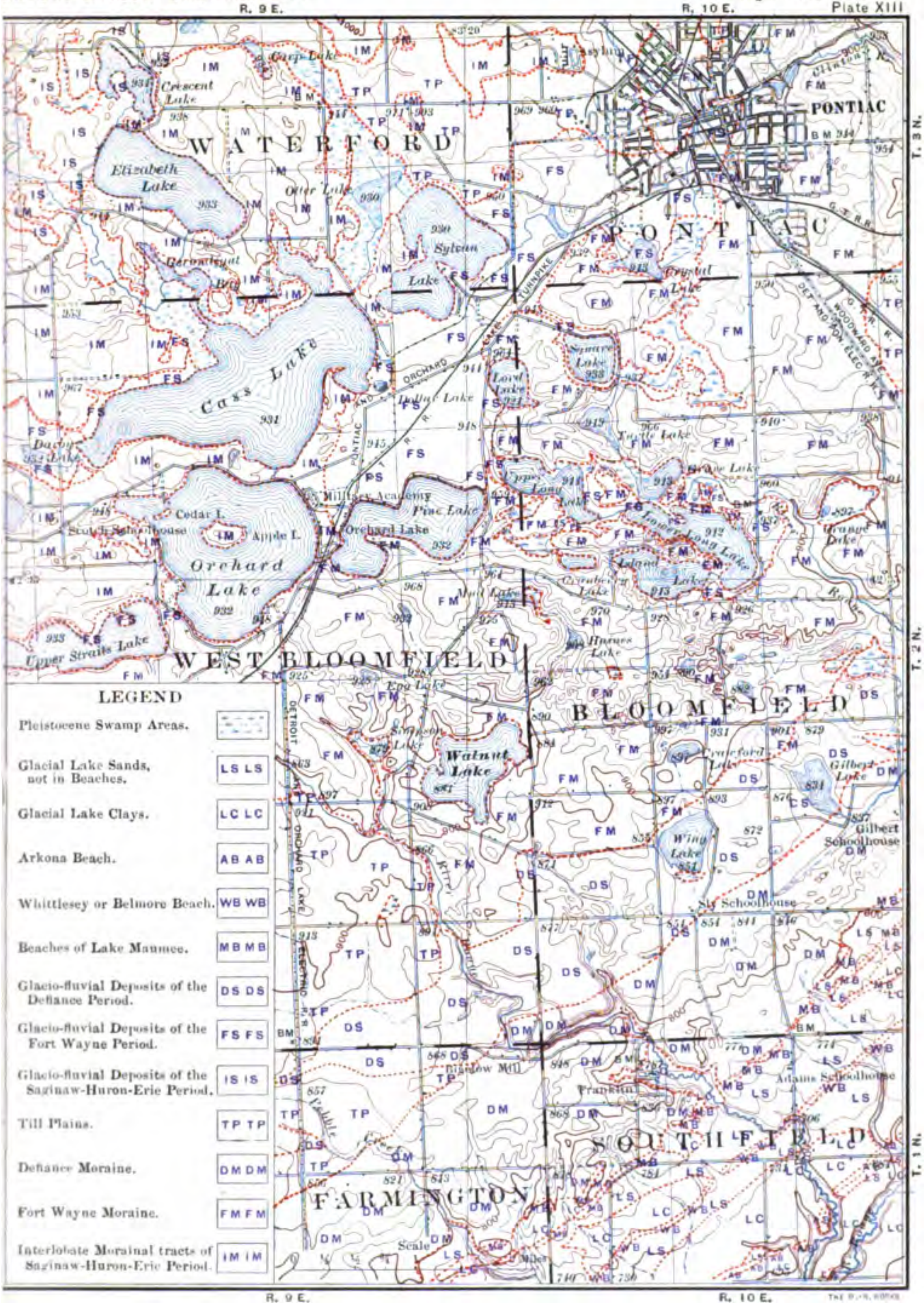
Plate XIII

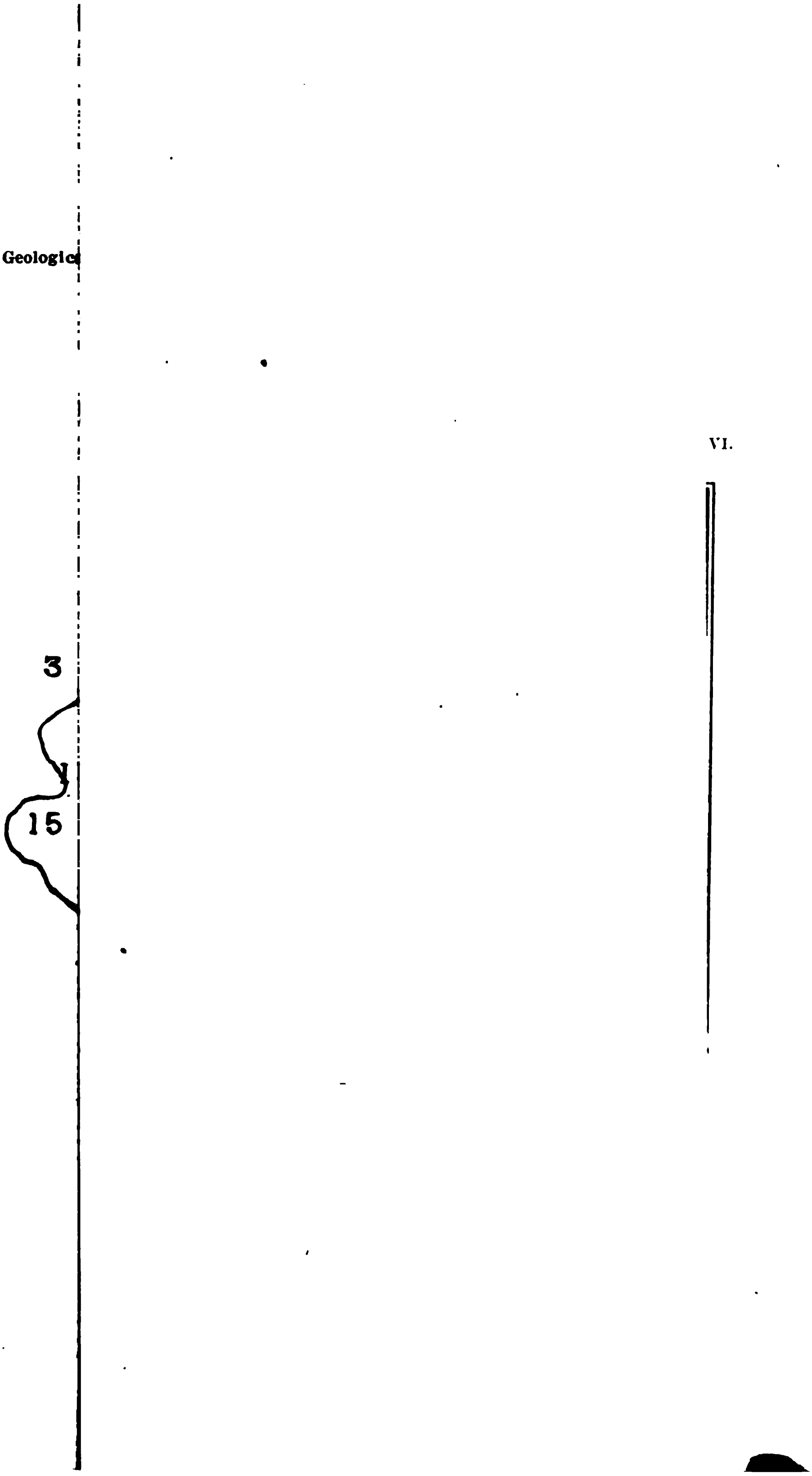


SURFACE GEOLOGY OF THE VICINITY OF WALNUT LAKE

Compiled by Charles A. Davis, from a manuscript map by Frank Leverett, U. S. Geological Survey.

Topographic base by the United States Geological Survey, 1906. Contour interval 20 feet. Datum is mean sea level.

Geological Survey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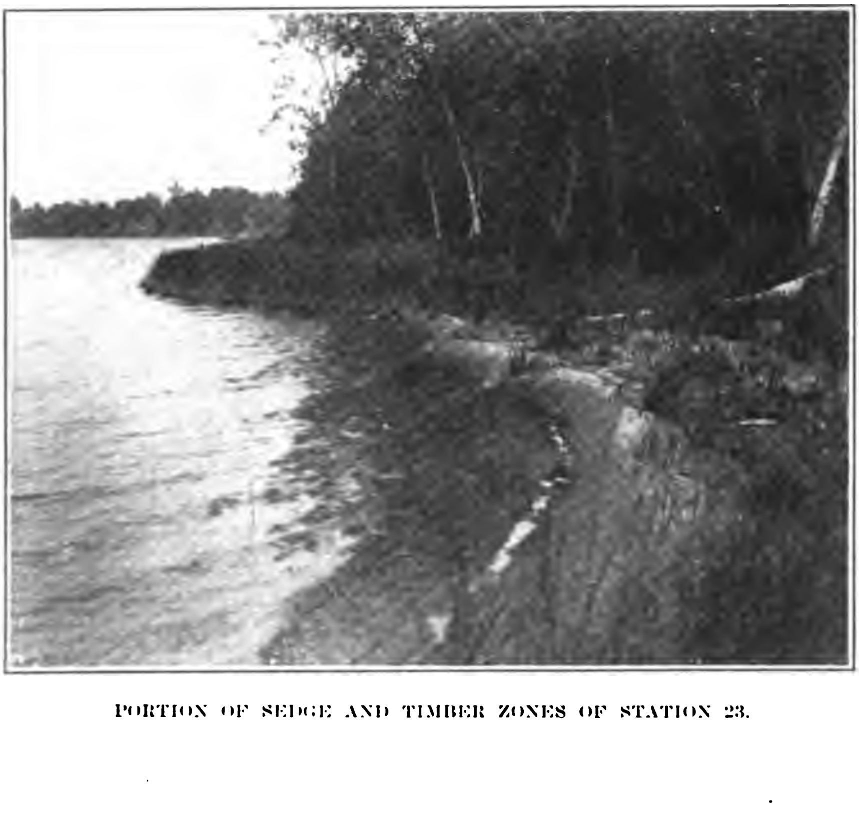
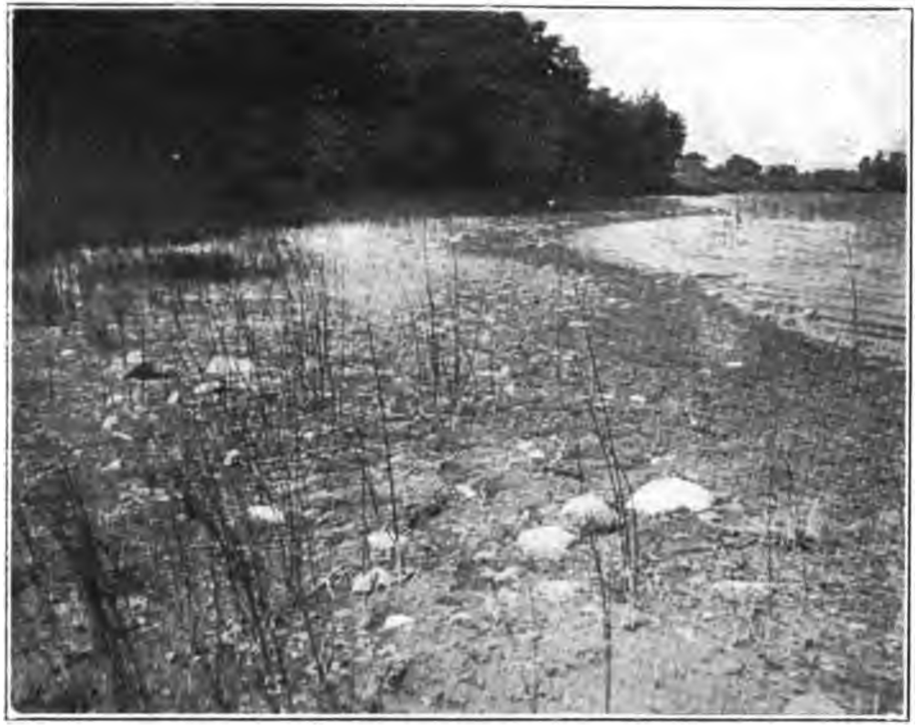
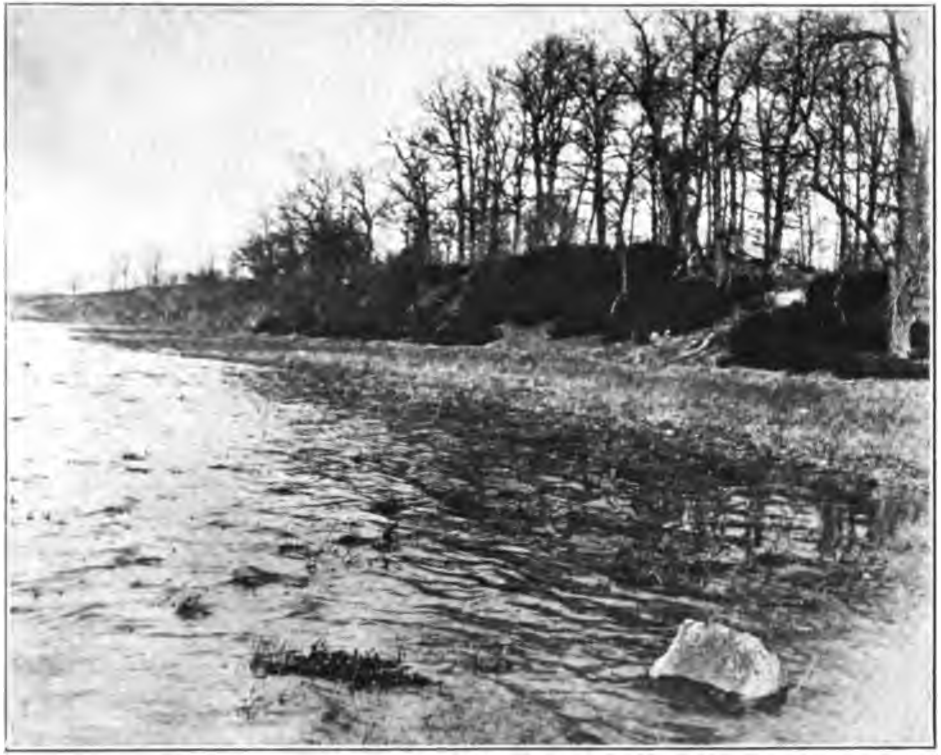


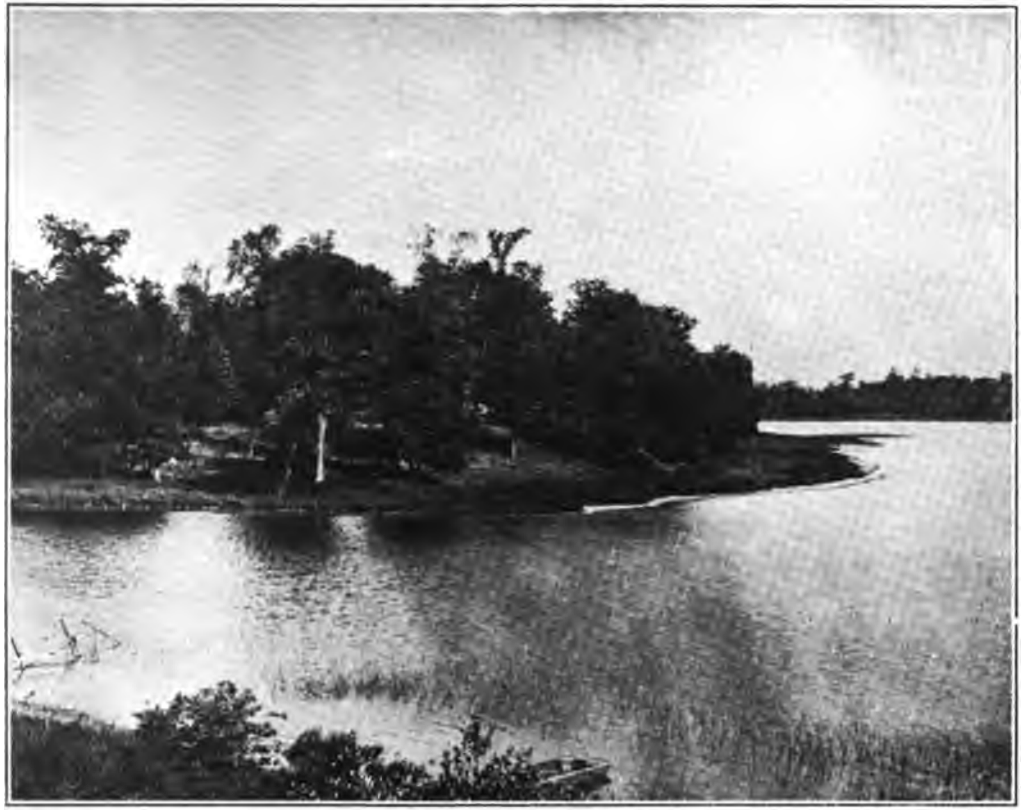
PORTION OF SEDGE AND TIMBER ZONES OF STATION 23.



BEACH OF STATION 23, SHOWING ENCROACHING VEGETATION FROM SEDGE ZONE.

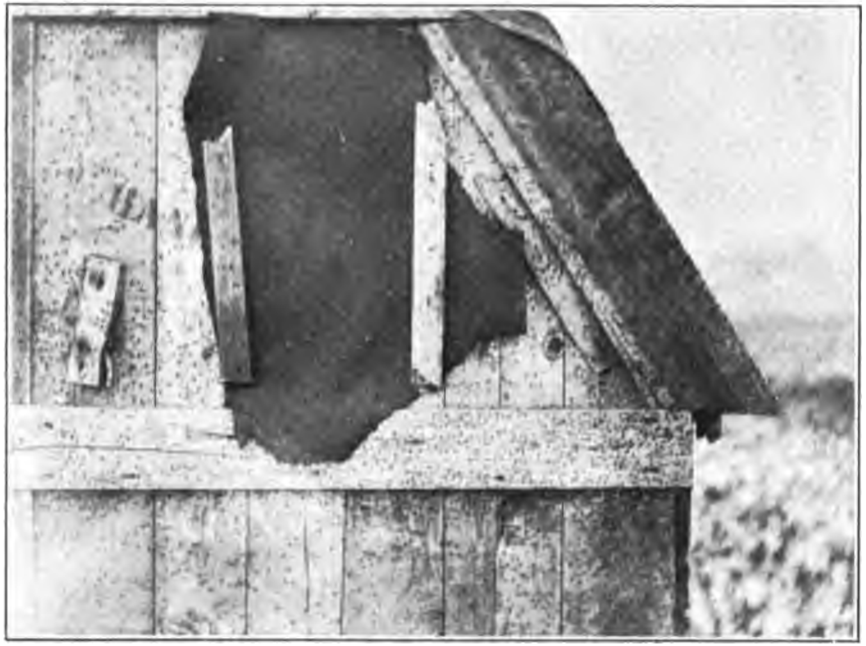


STATION 32 IN APRIL.

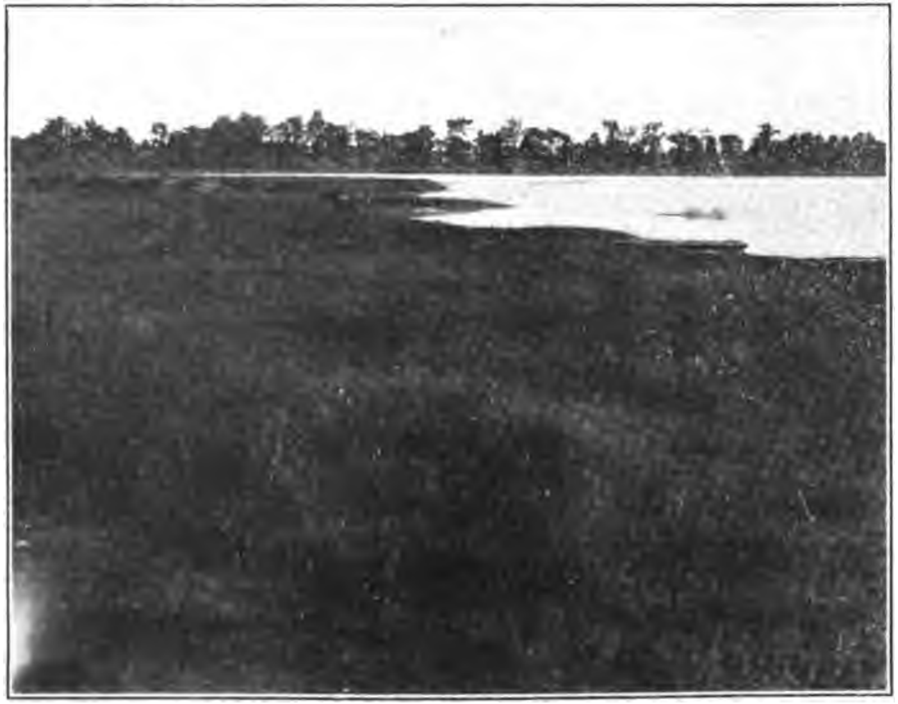


STATION 32, LOOKING EAST FROM HILL ON WEST SIDE OF THE NORTH BAY.

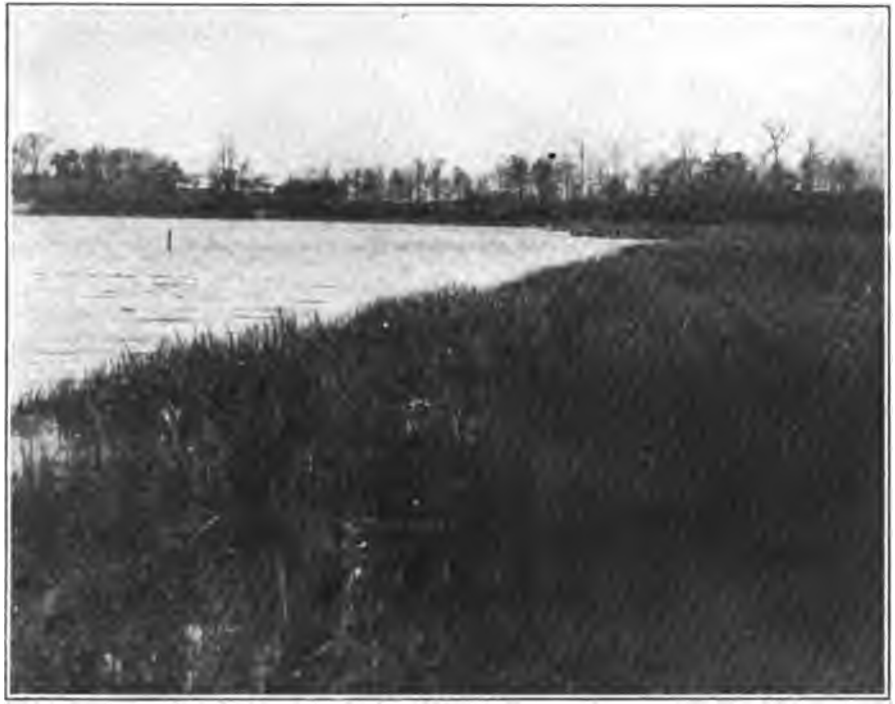
STATION 3, LOOKING SOUTH FROM STATION 1.



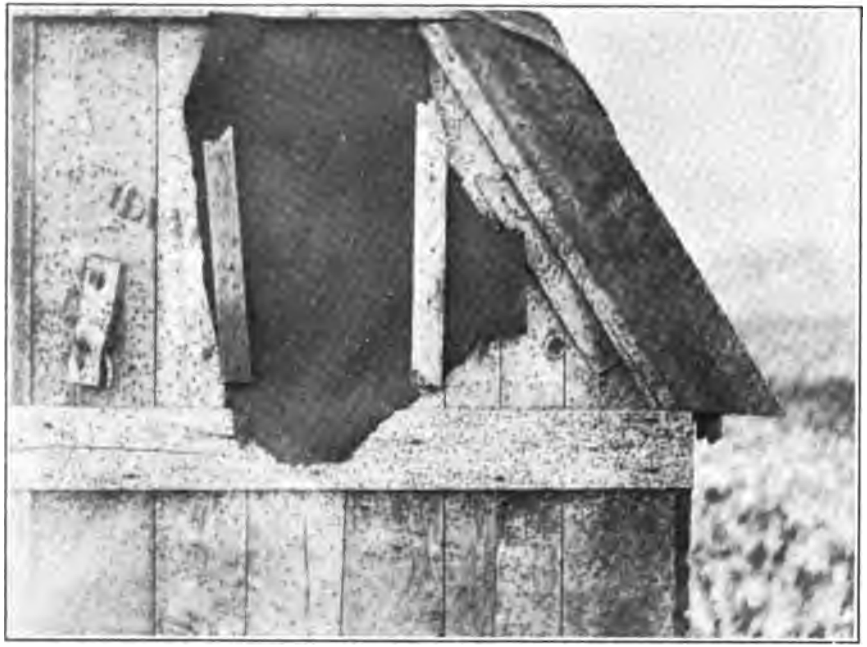
MIDGES ON END OF SPEAR HOUSE (PIANO BOX) AT STATION 3.



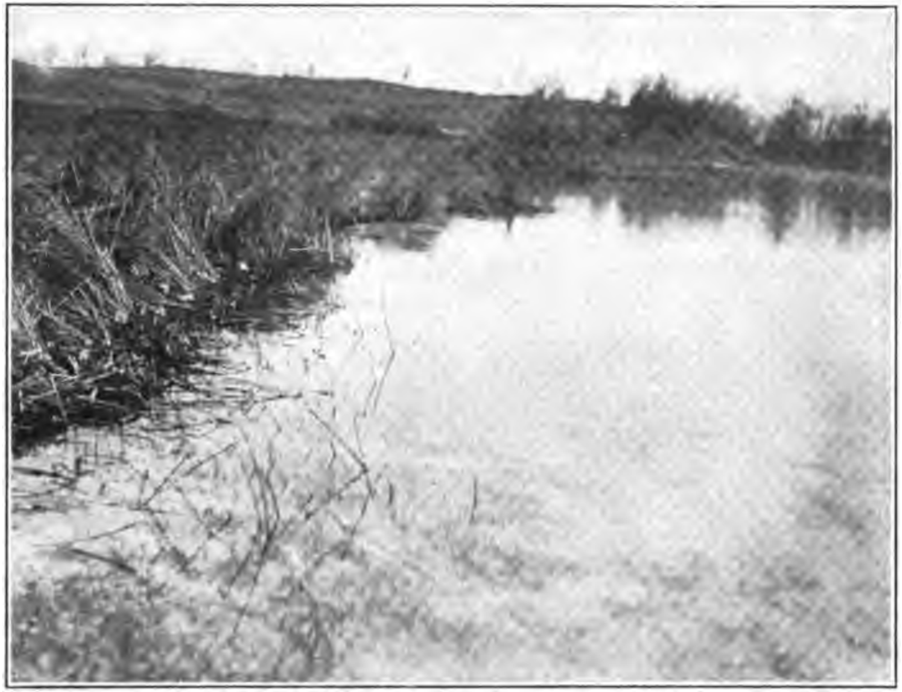
STATION 46, LOOKING SOUTH FROM STATION 40.



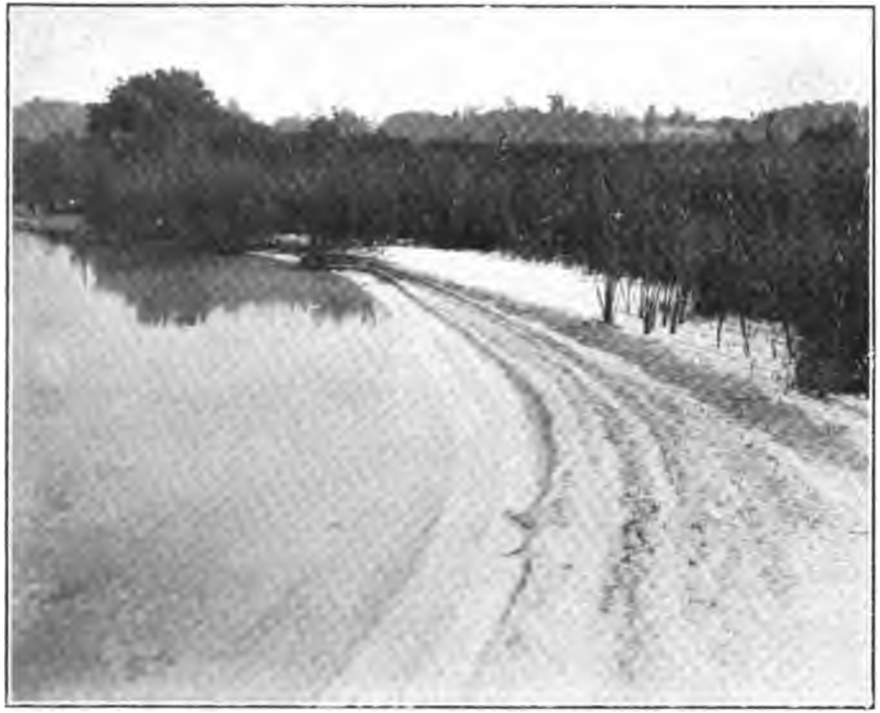
STATION 3, LOOKING SOUTH FROM STATION 1.



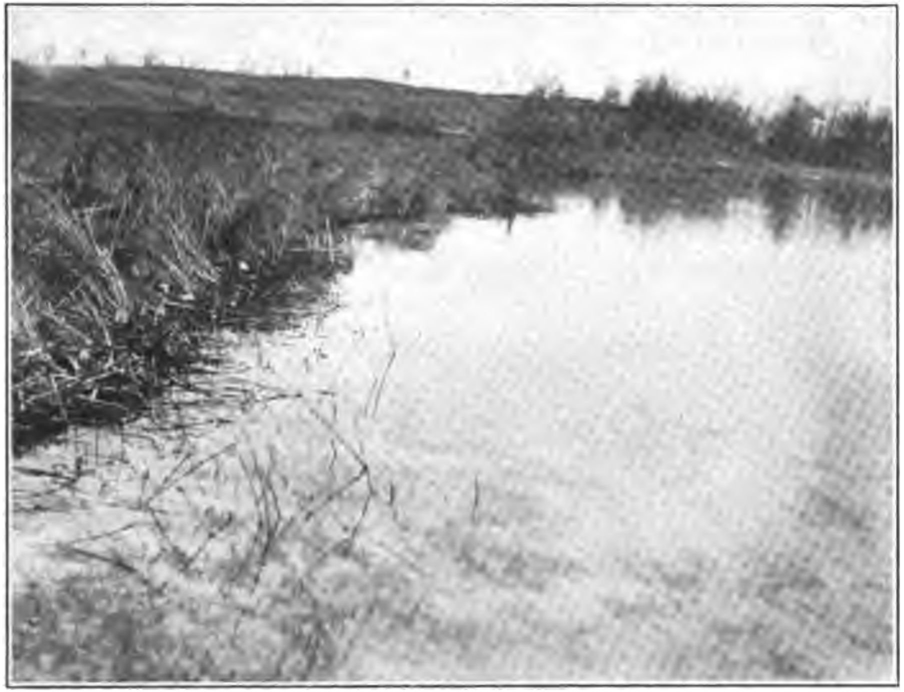
MIDGES ON END OF SPEAR HOUSE (PIANO BOX) AT STATION 3.



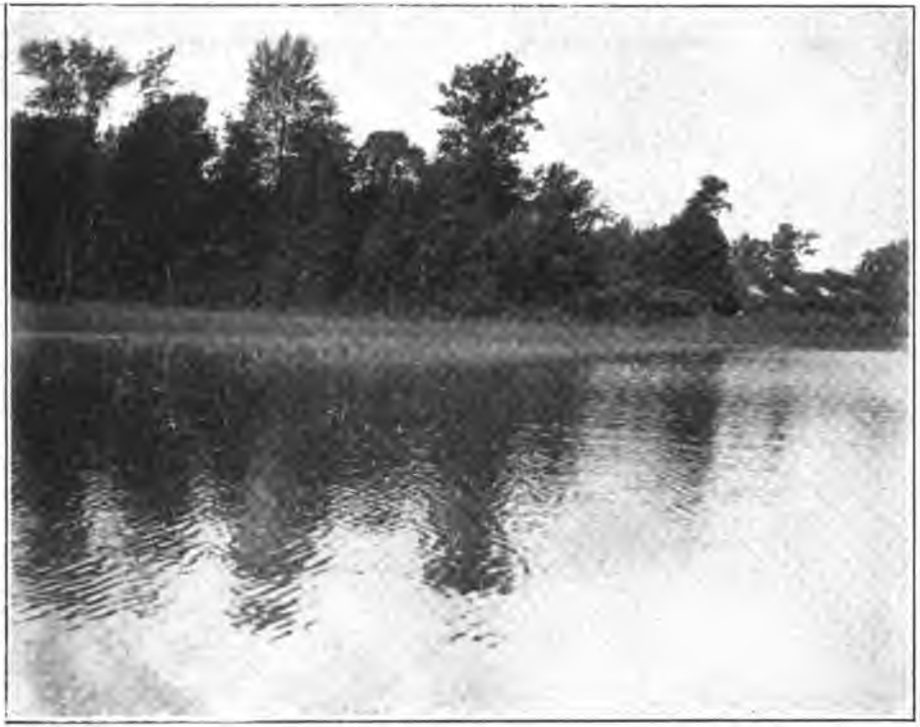
MARSHY SHORE OF STATION 16 IN APRIL.



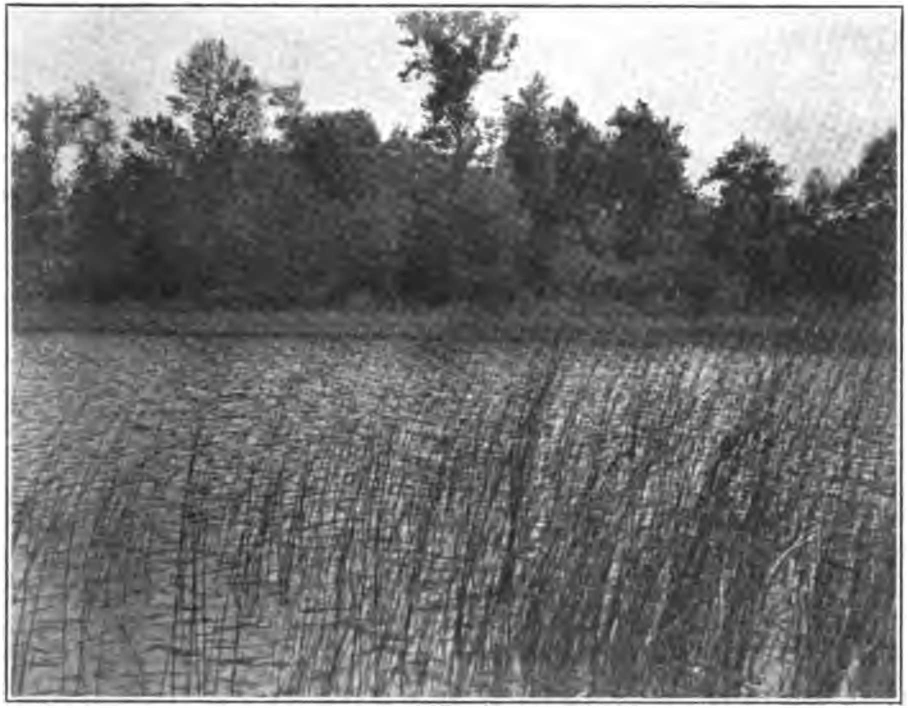
BEACH AT STATION 16, SHOWING SORTED FRAGMENTS.



MARSHY SHORE OF STATION 16 IN APRIL.

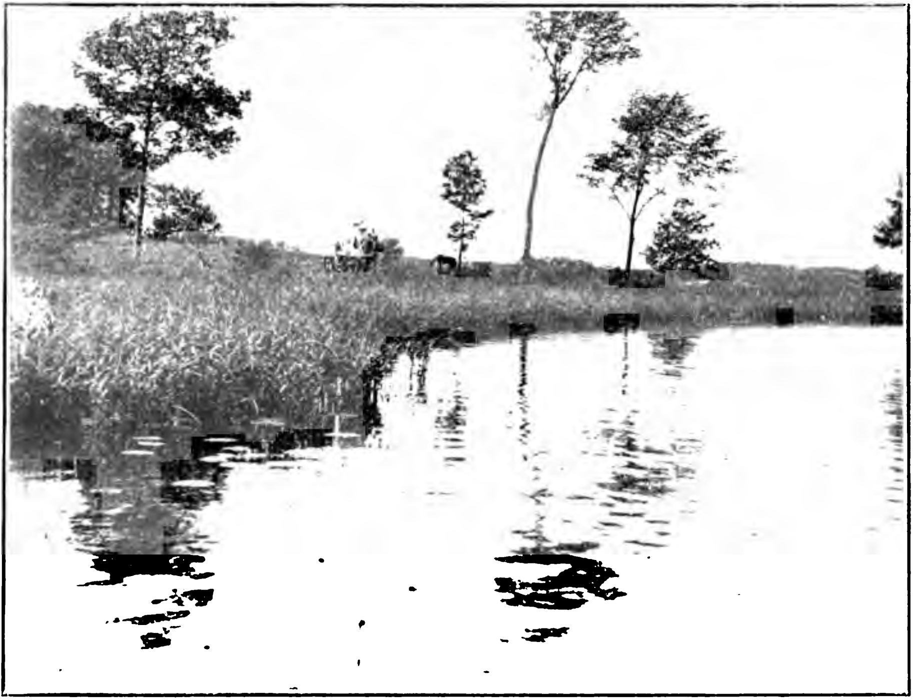


STATION 15, LOOKING WEST.

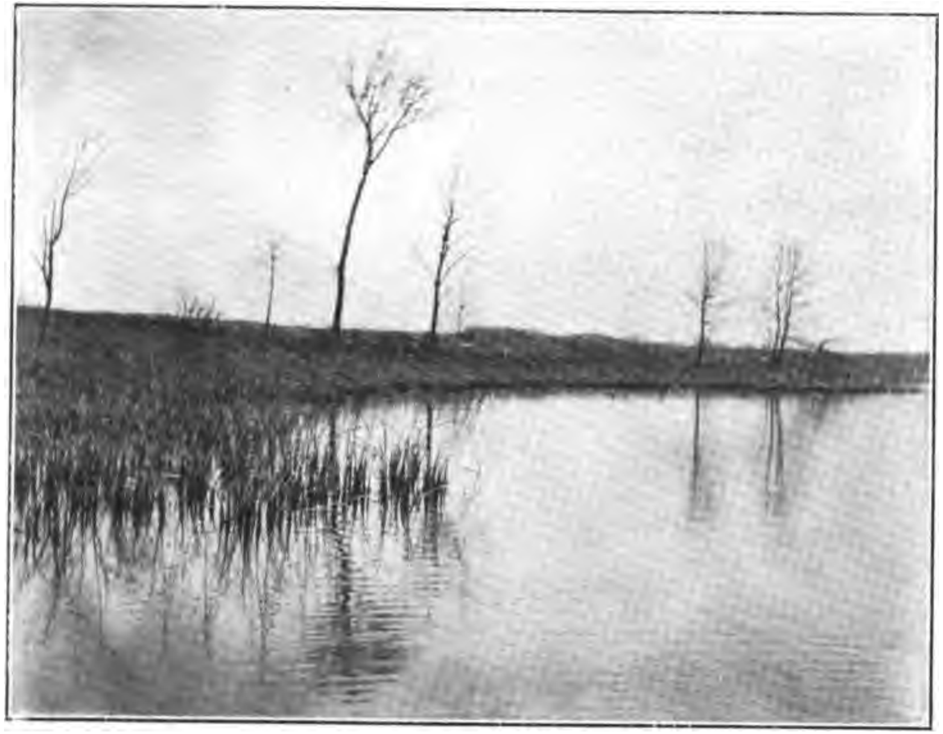


STATION 15, LOOKING SOUTH.

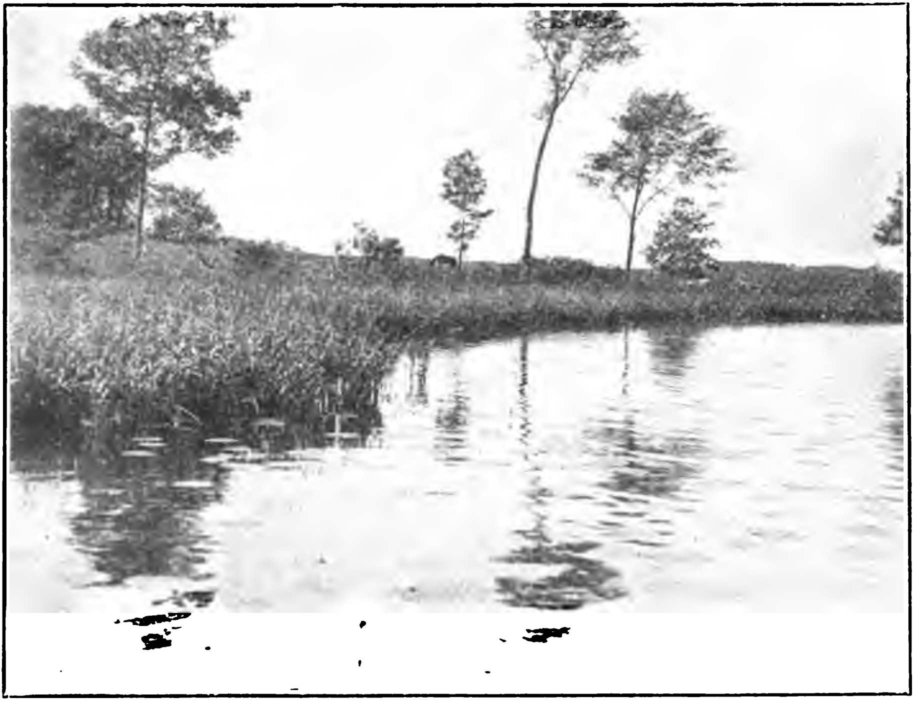
STATION 15, LOOKING WEST.



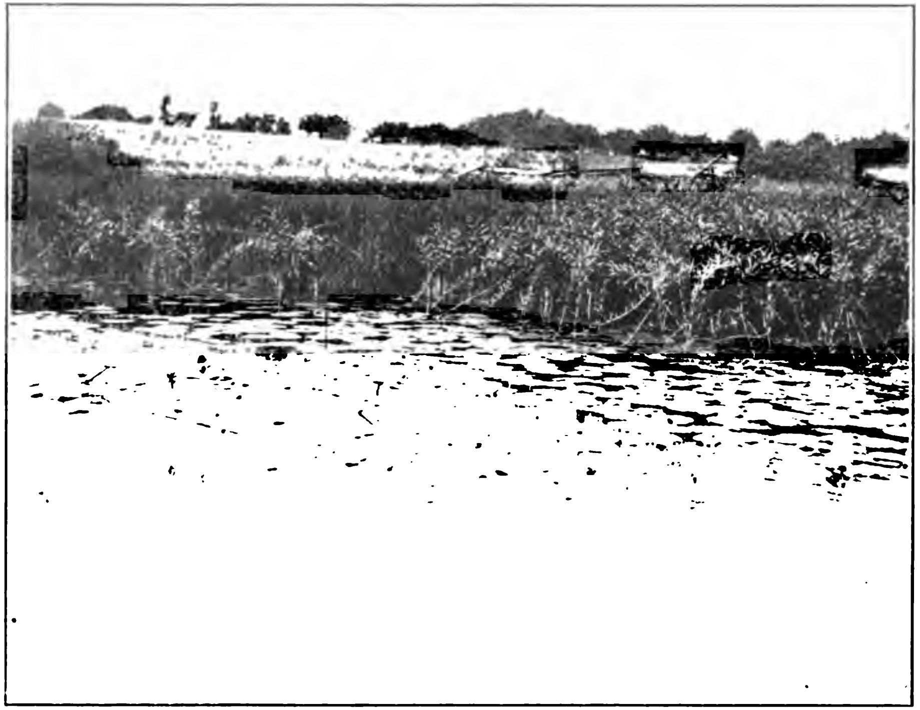
STATION 31 IN JUNE.



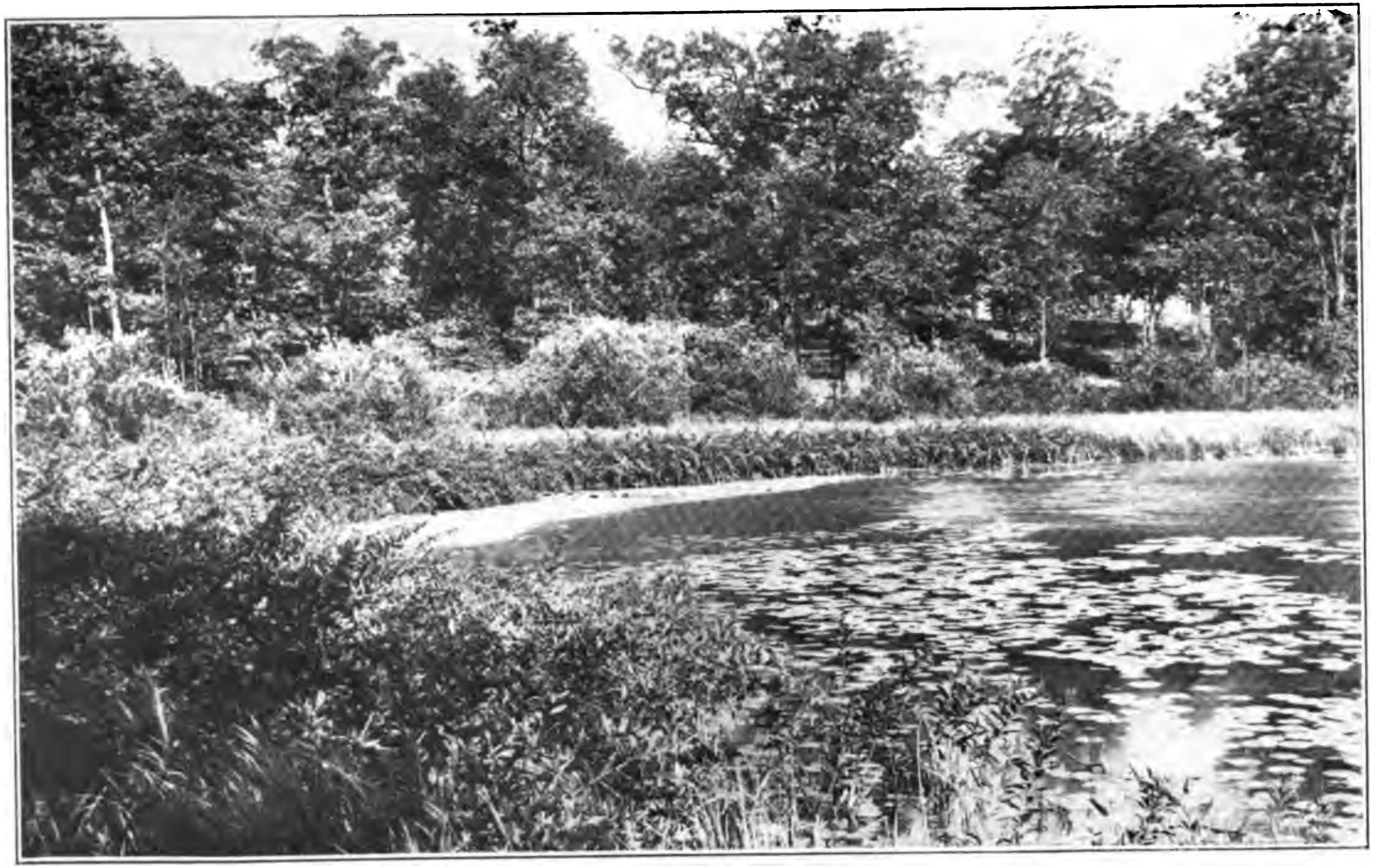
STATION 31 IN APRIL.



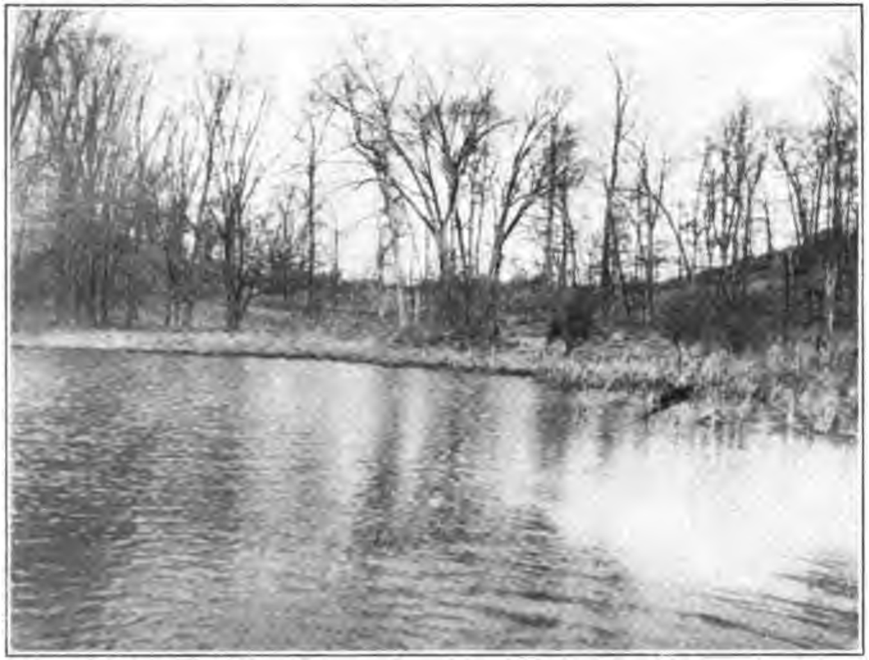
STATION 31 IN JUNE.



STATION 31 IN AUGUST, SHOWING LOOSESTRIFE PLANTS AND PORTION OF LILY ZONE.

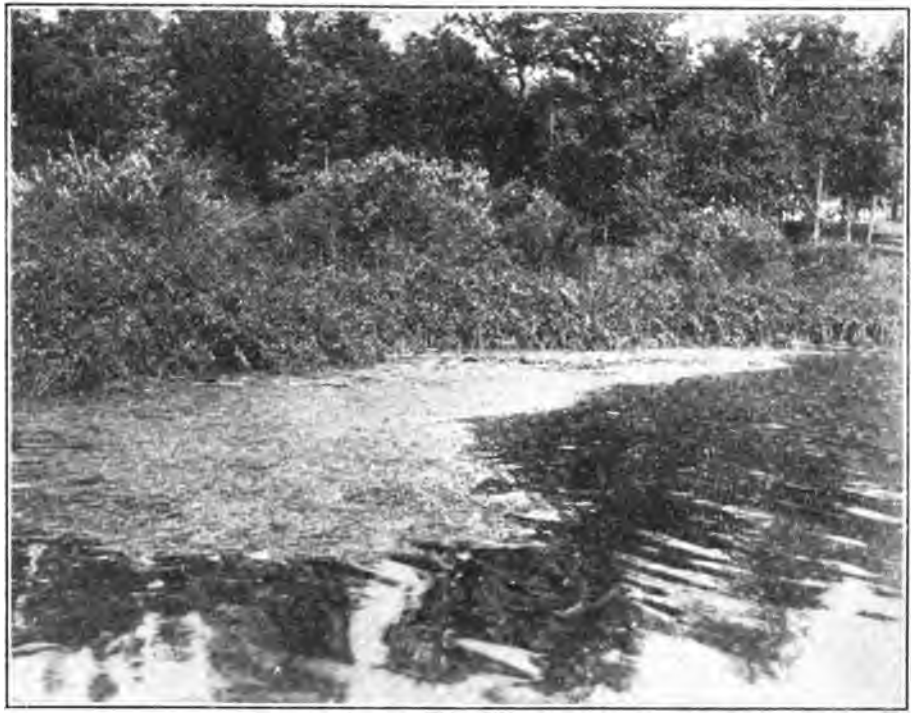


STATION 26, LOOKING EAST IN AUGUST.

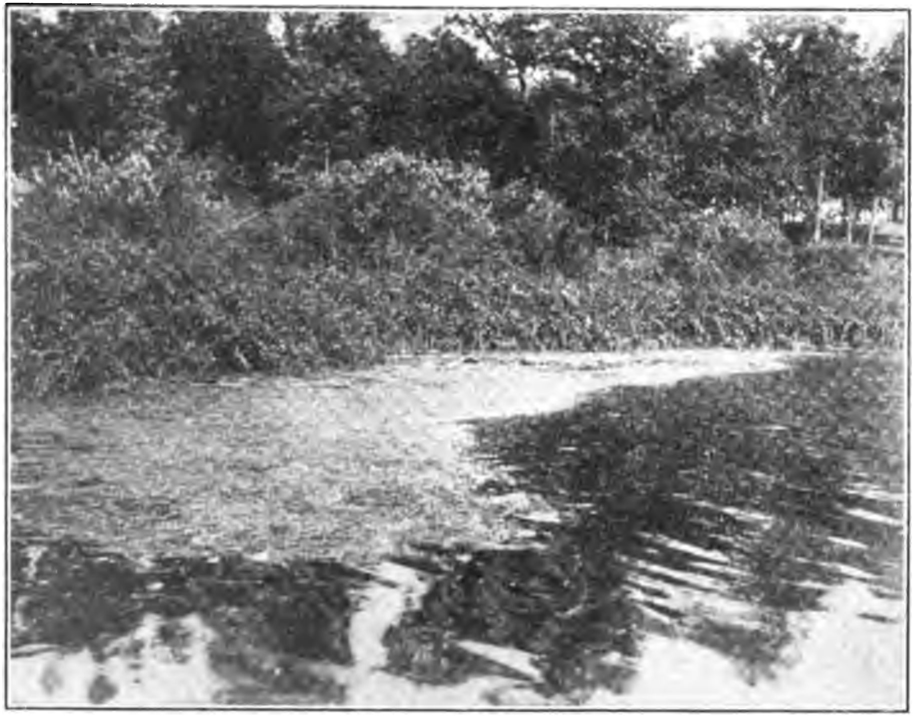


STATION 26, LOOKING NORTH IN APRIL.

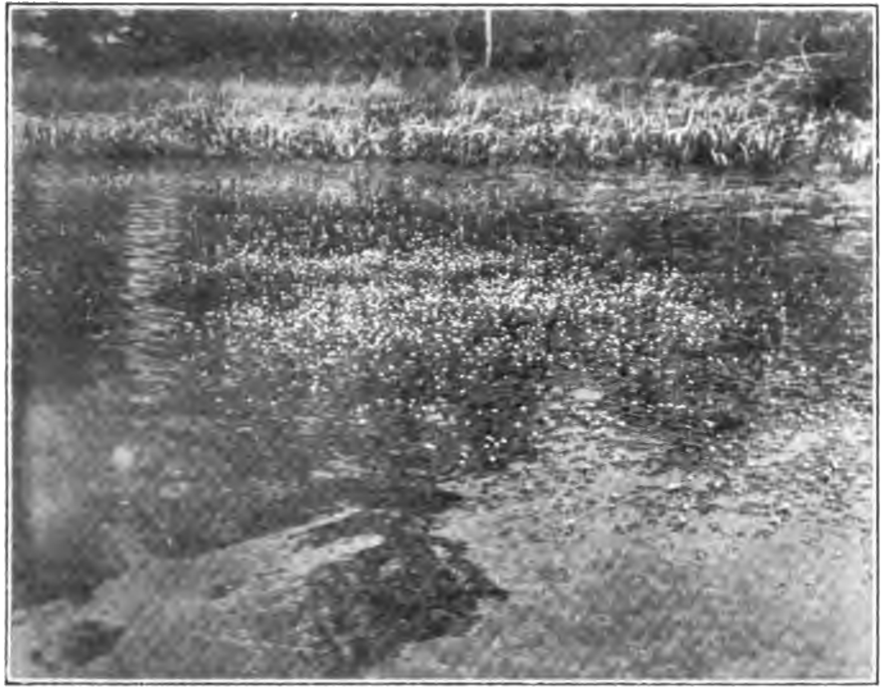
STATION 26, LOOKING NORTH IN JUNE, SHOWING PATCH OF WATER CROWFOOT.



STATION 26 IN AUGUST, SHOWING MASS OF FLOATING CROWFOOT PLANTS DETACHED AND WASHED AGAINST LOOSESTRIFE.

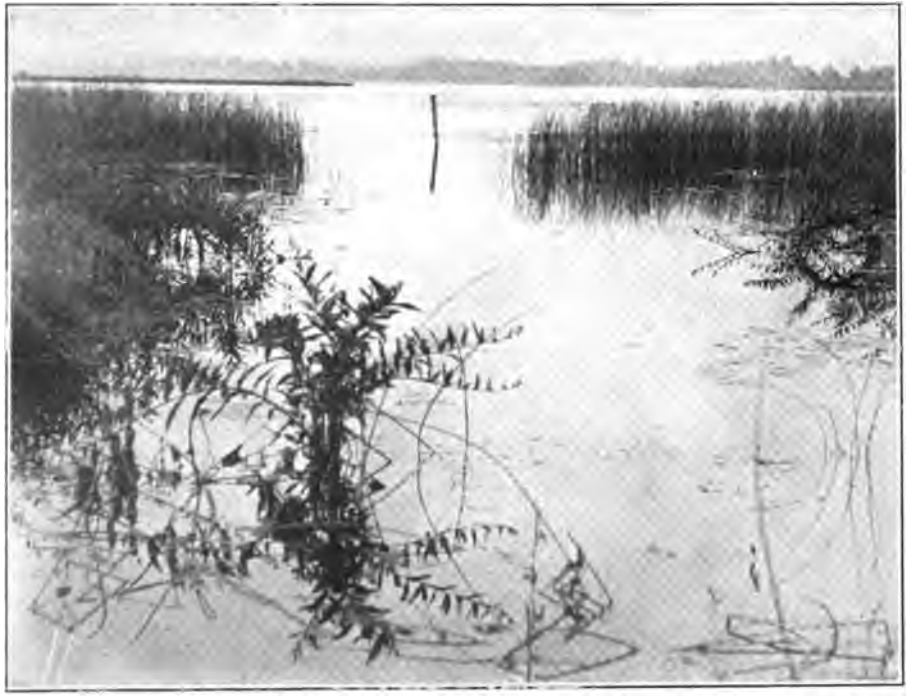


STATION 26 IN AUGUST, SHOWING MASS OF FLOATING CROWFOOT PLANTS DETACHED AND WASHED AGAINST LOOSESTRIFE.

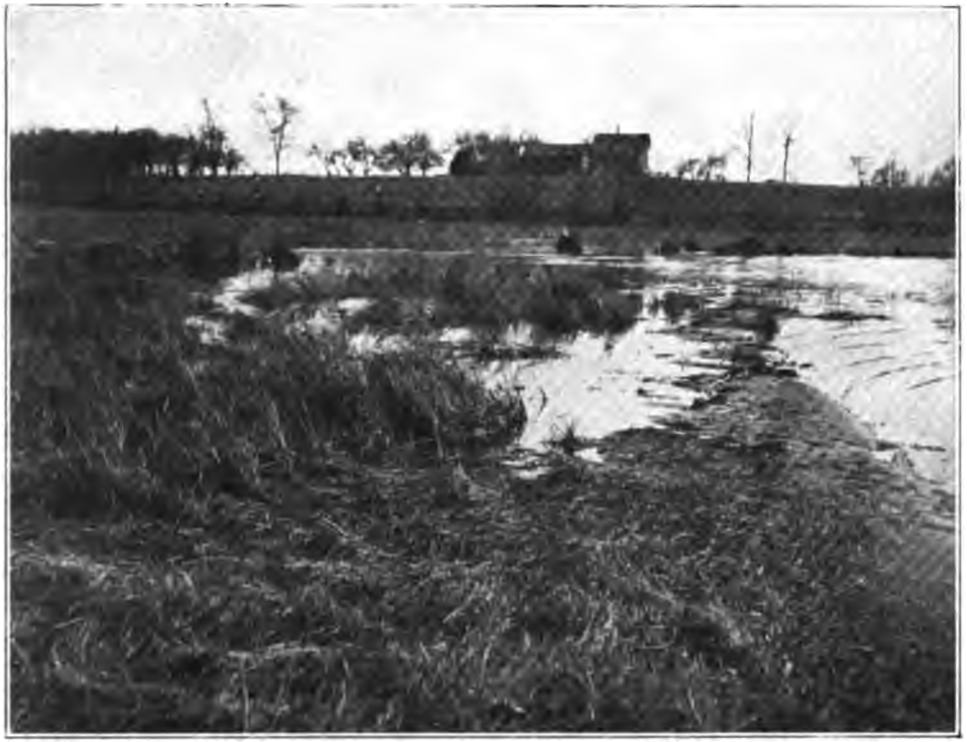


WATER CROWFOOT AT STATION 26, JUNE 3, 1906.

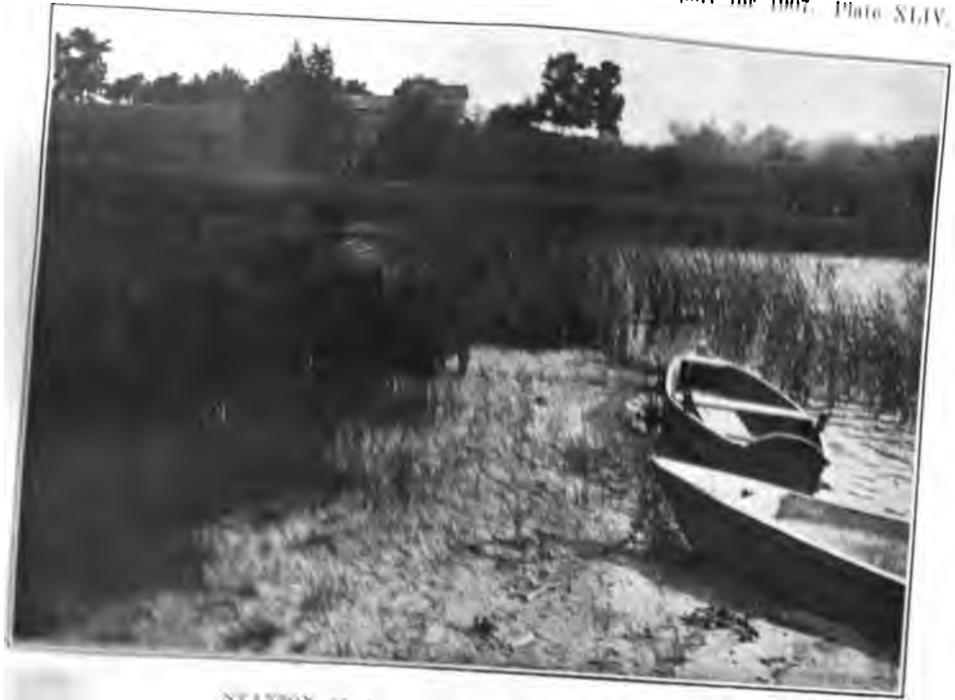
STATION 7. LOOKING EAST OUT INTO LAKE.



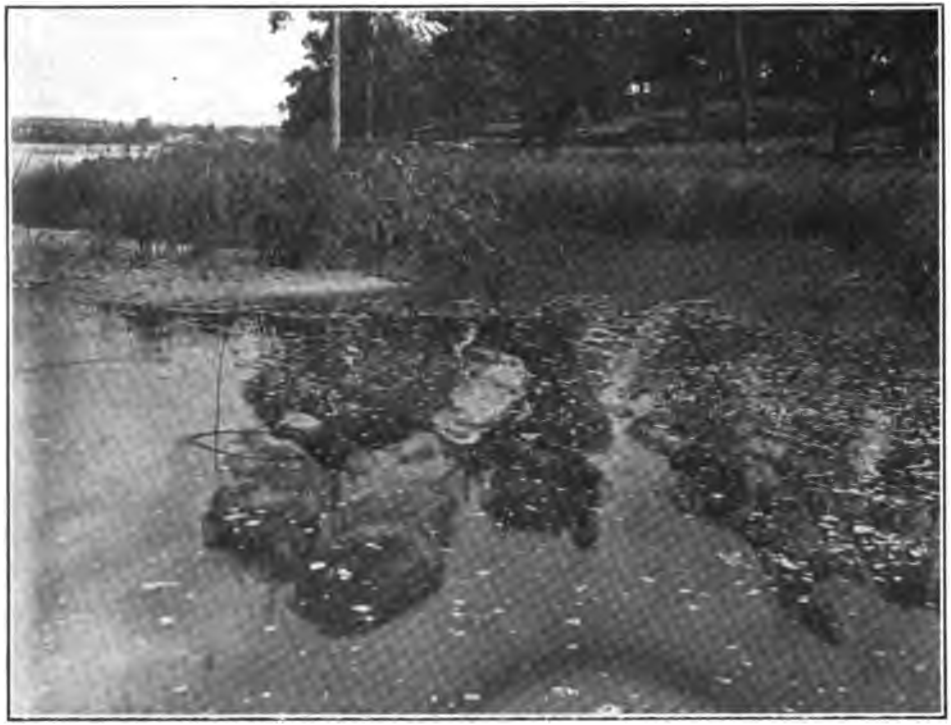
STATION 7. LOOKING EAST OUT INTO LAKE.



STATION 41, LOOKING SOUTH IN APRIL.



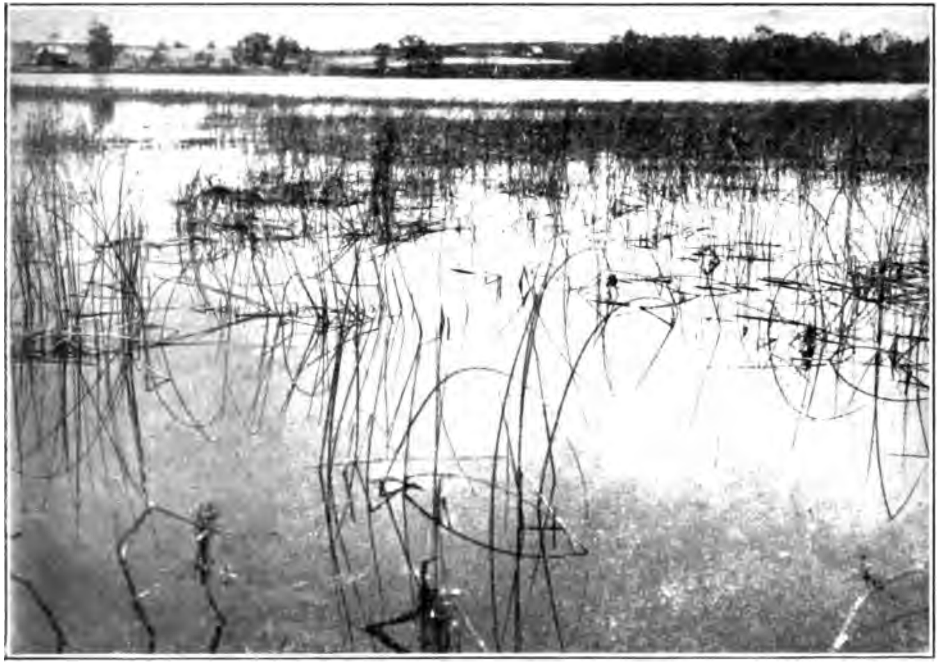
STATION 41. LOOKING SOUTH IN SUMMER.



STATION 41, LOOKING NORTH, SHOWING AQUATIC VEGETATION CLOGGING NORTH LOBE OF BAY.

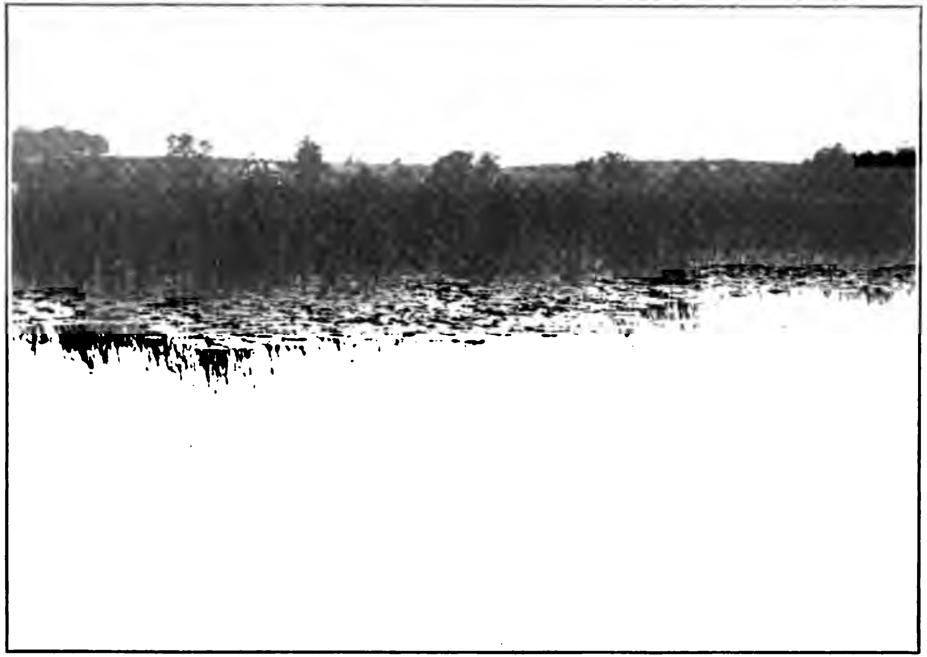
Geological Survey of Michigan. Annual Report for 1907. Plate XLVI.

[illegible] LOOKING SOUTHEAST"

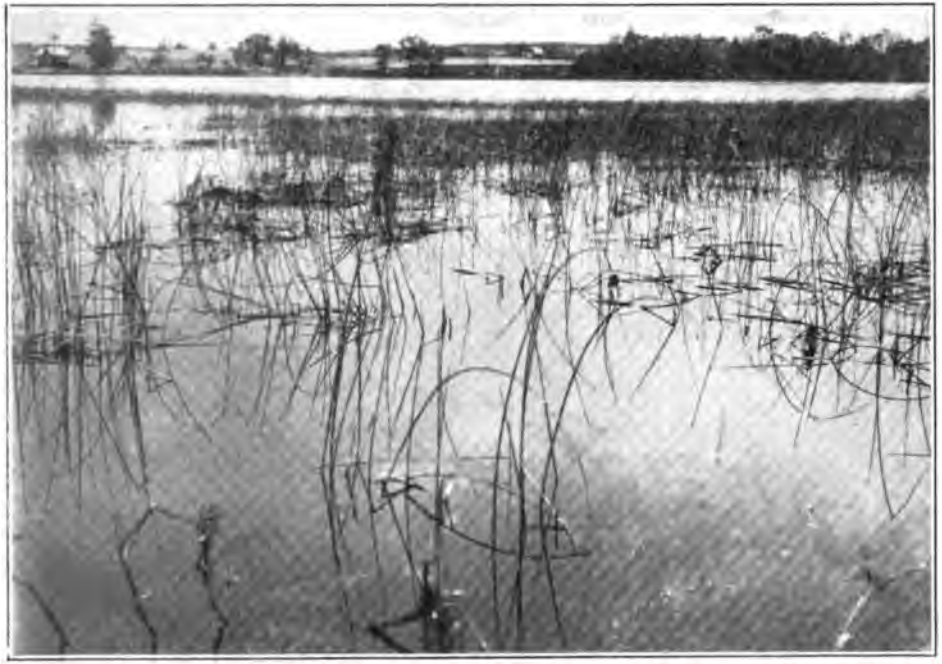


PORTION OF STATION 54 WHERE BLACK BASS NESTS WERE FOUND MOST ABUNDANT.

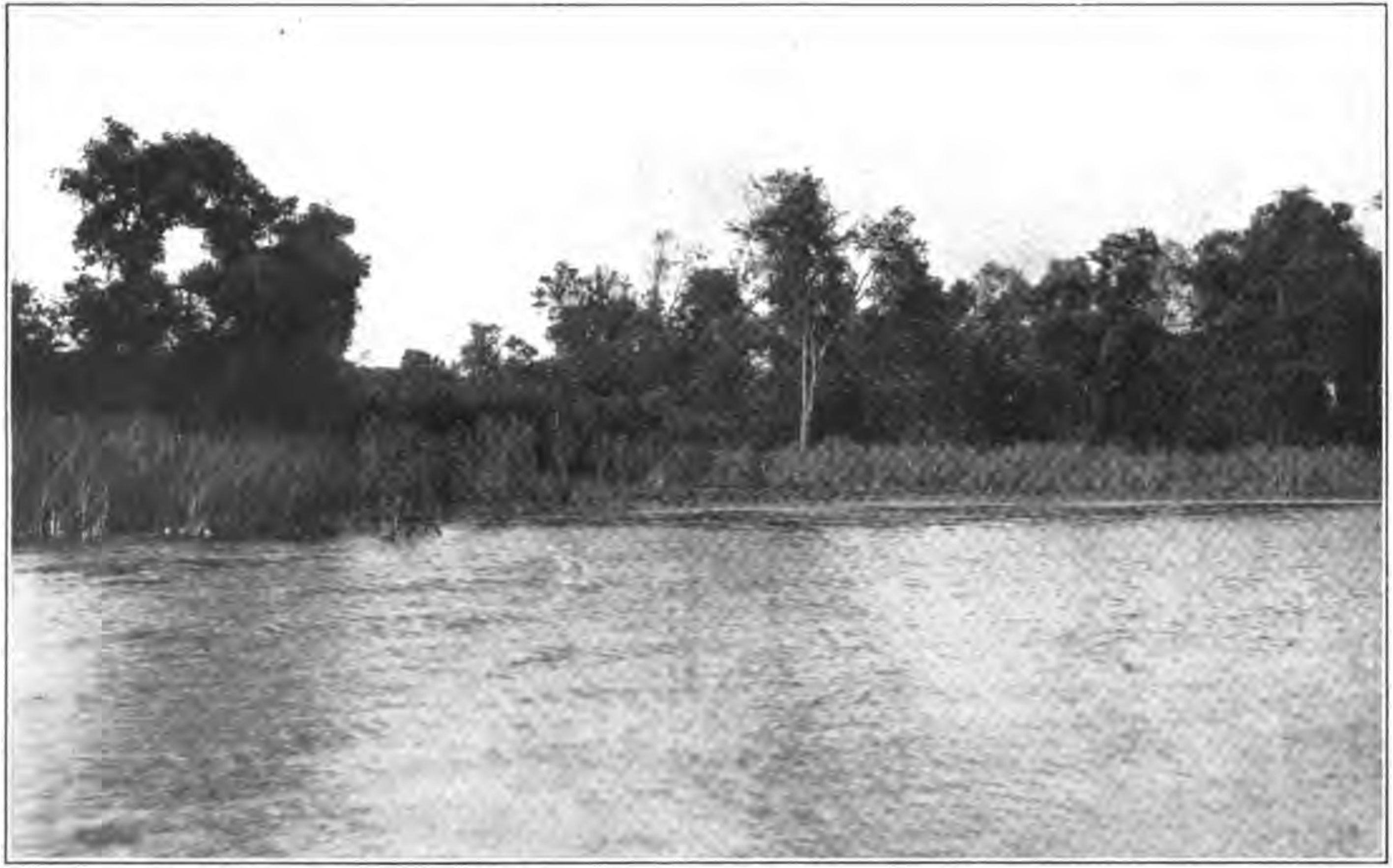
STATION 54. VEGETATION AT MARGIN OF STONEWORT COVERED BOTTOM POOL.



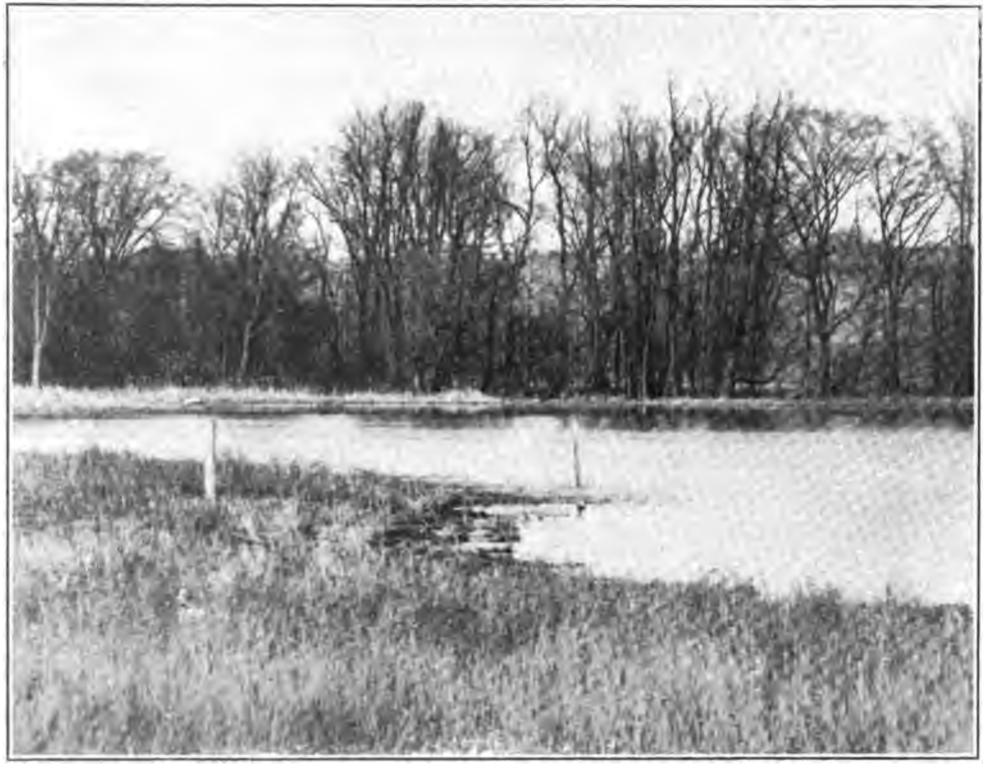
STATION 54. VEGETATION AT MARGIN OF STONEWORT COVERED BOTTOM POOL.



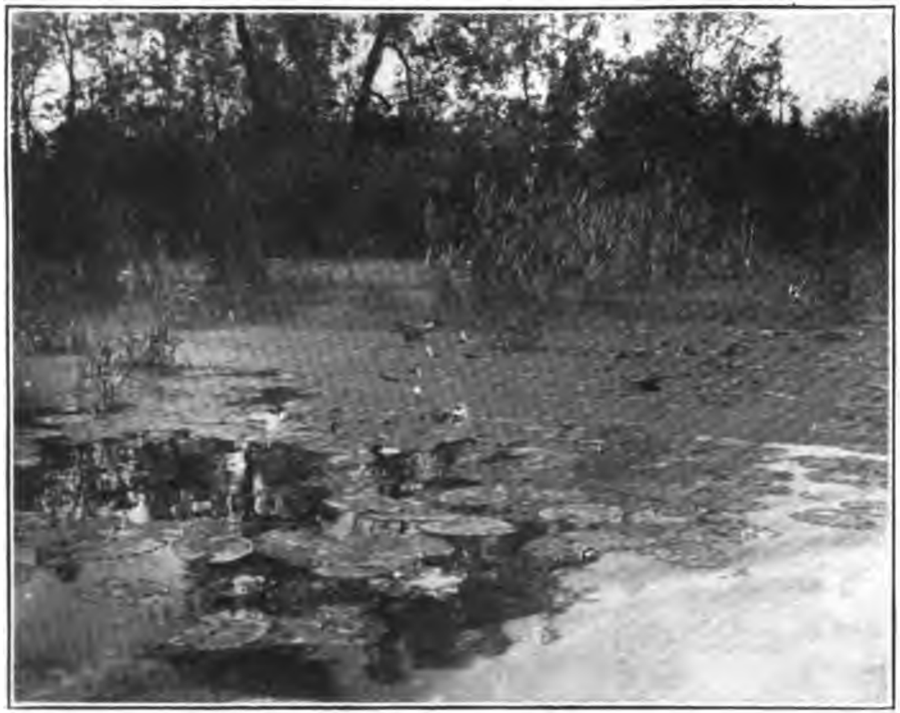
PORTION OF STATION 54 WHERE BLACK BASS NESTS WERE FOUND MOST ABUNDANT.



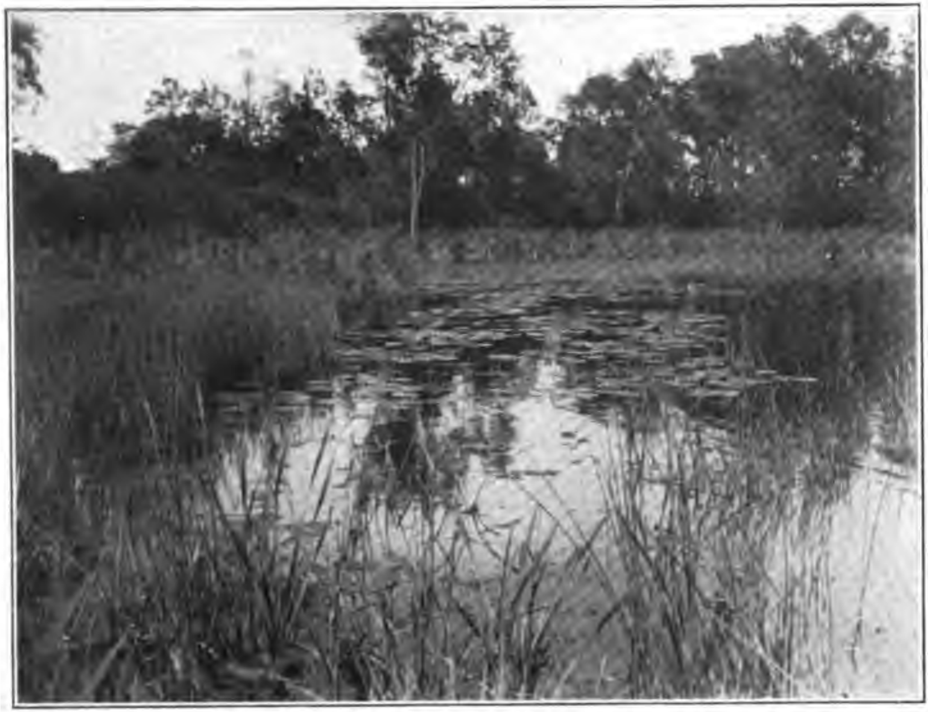
STATION 40, LOOKING NORTHEAST IN AUGUST.



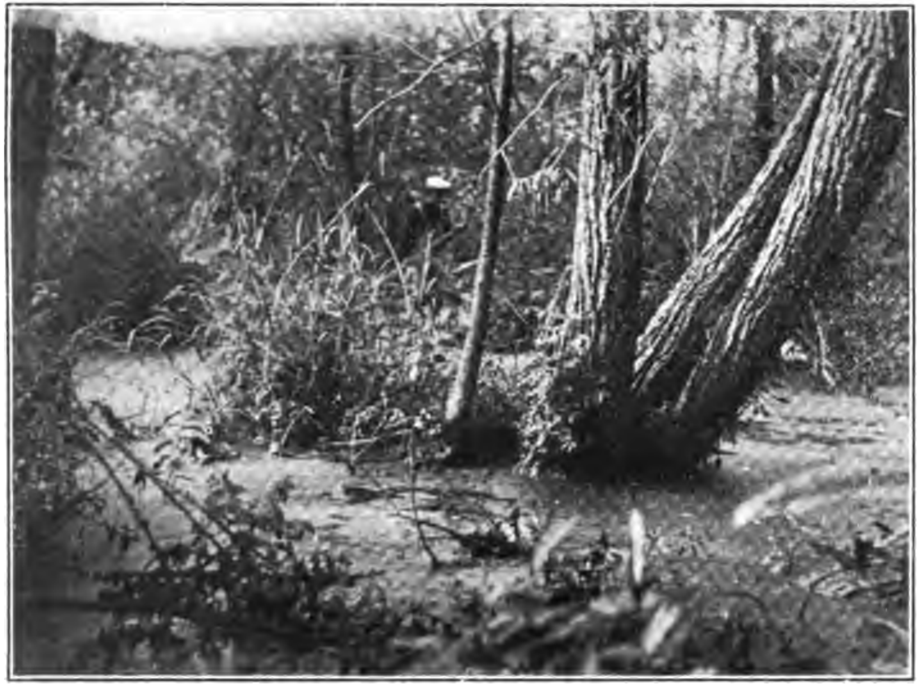
STATION 40 (BACKGROUND) IN APRIL, LOOKING NORTHEAST.



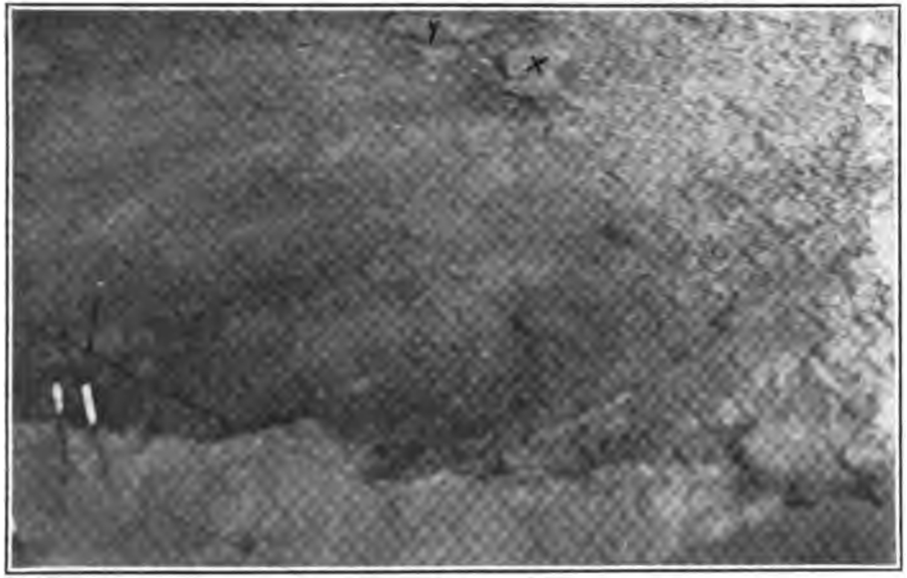
STATION 40. ZONES OF PLANT LIFE, NEAR CENTER OF STATION.



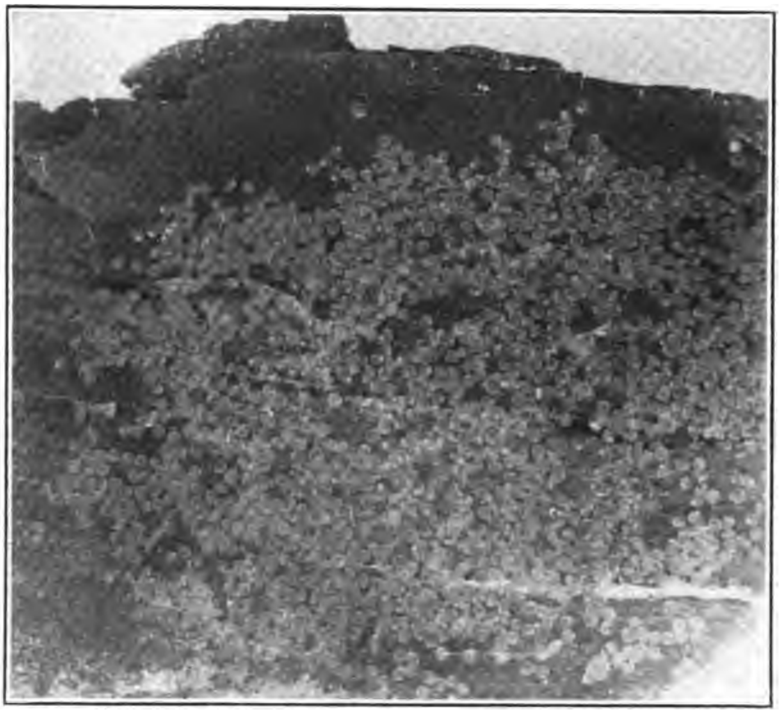
STATION 40, SHOWING PLANT ZONES.



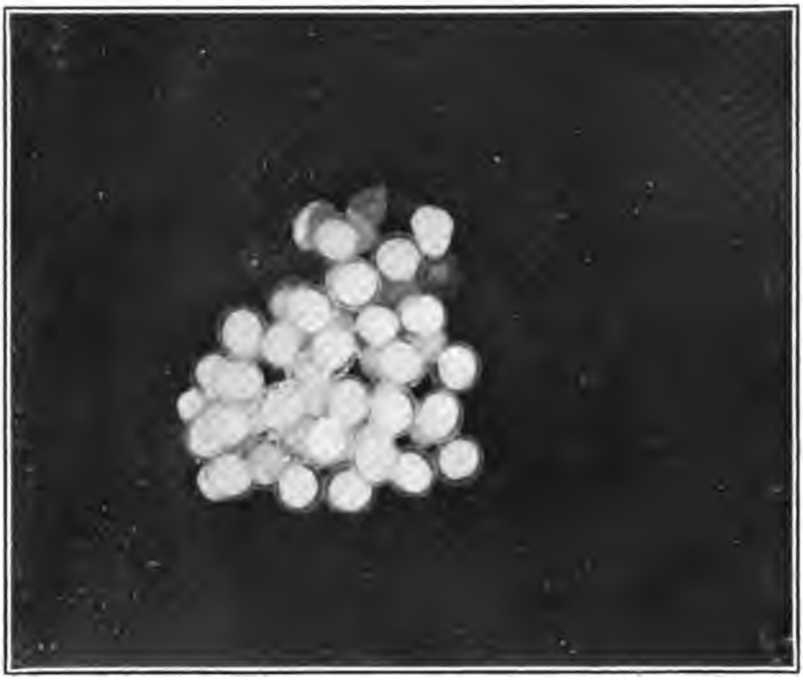
STATION 40. INTERIOR OF SWAMP ZONE.



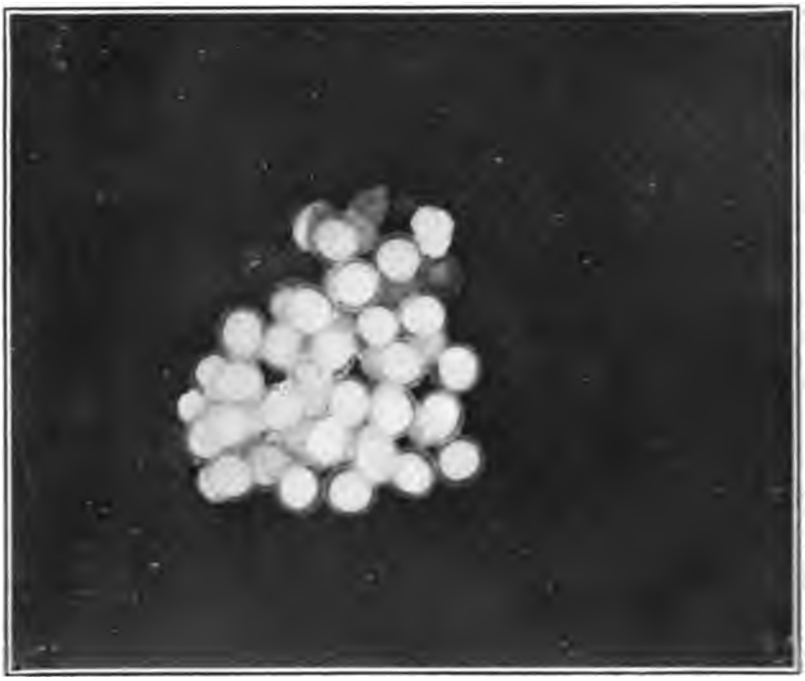
PORTION OF GRAVELLY BOTTOM STATION 23, SHOWING NESTING PLACE OF BLUNT-NOSED MINNOW (STONE MARKED Y) AND MILLER'S THUMB (STONE MARKED X).



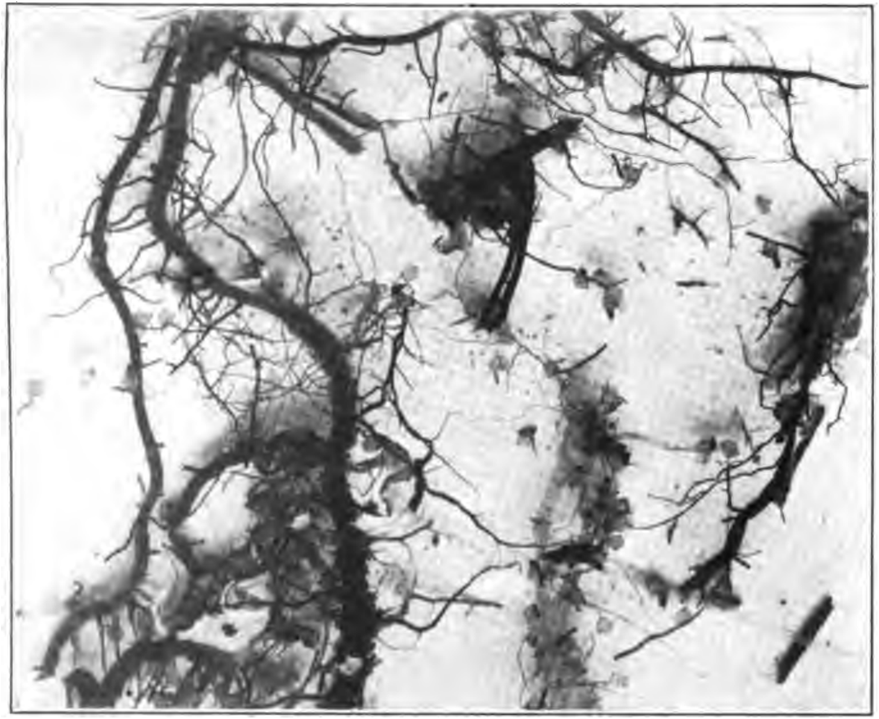
EGGS OF BLUNT-NOSED MINNOW ON PIECE OF BARK. STATION 35.



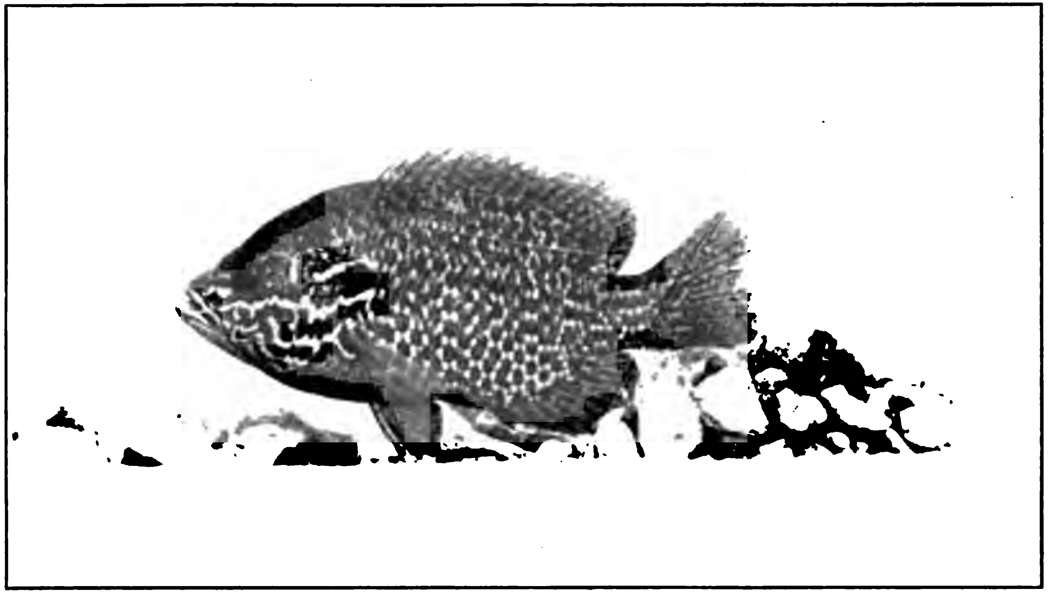
EGGS OF TADPOLE STONE-CAT X2.



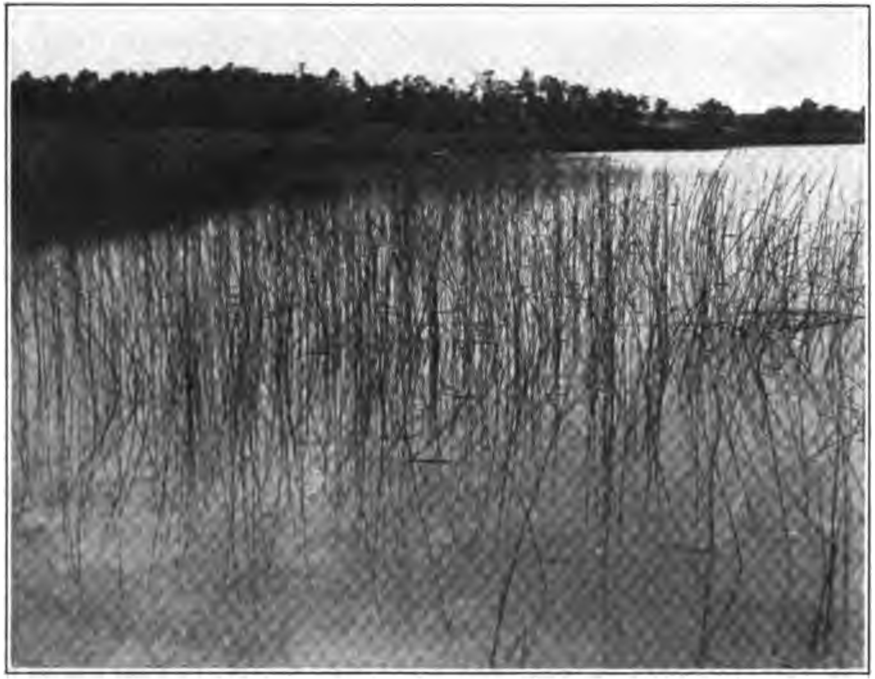
EGGS OF TADPOLE STONE-CAT X2.



EGGS OF BLUE-SPOTTED SUNFISH ATTACHED TO SEDGE ROOTS. STATION 9.



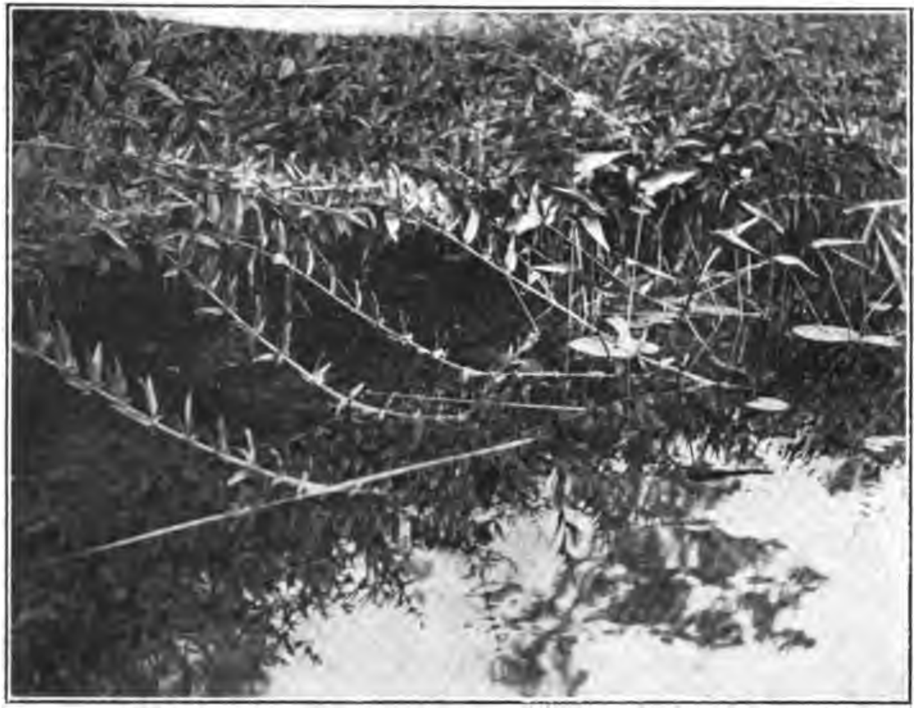
LEPORNIS EURYORNIS. LIVING FISH IN AQUARIUM.



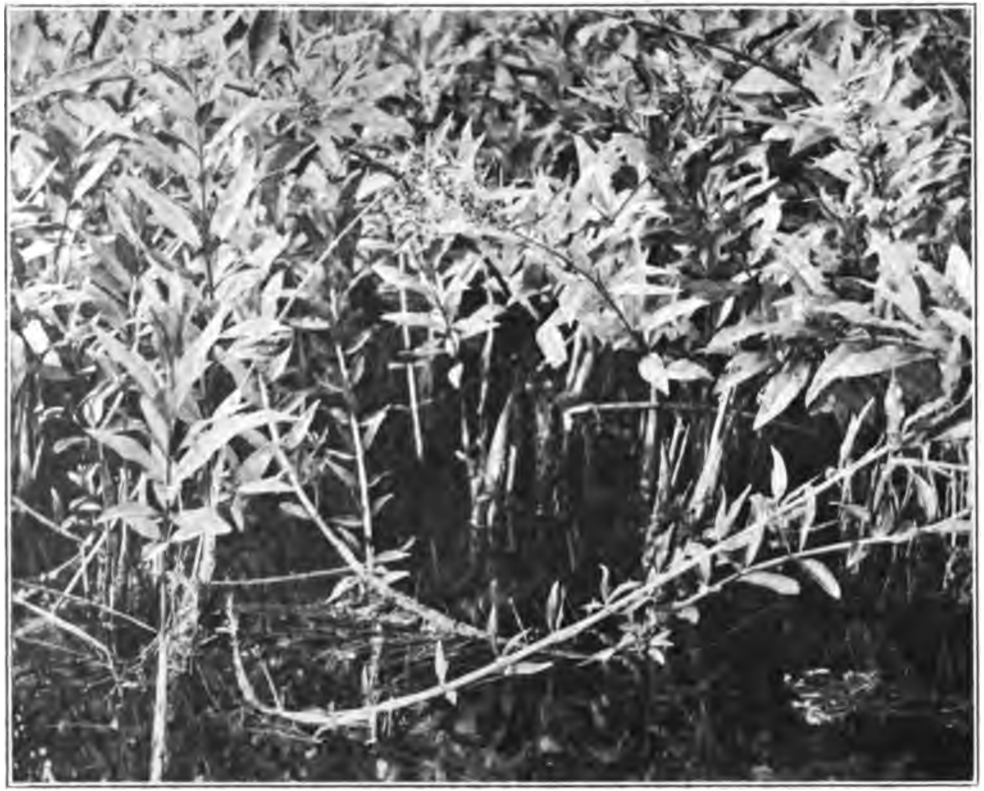
NESTING PLACE OF LONG-EARED SUNFISH. STATION 4.

LONG-EARED SUNFISH ABOUT NEST. TAKEN WHILE FISH WAS SWIMMING ABOUT NEST IN CIRCLE TO KEEP AWAY MINNOWS. STATION 4.

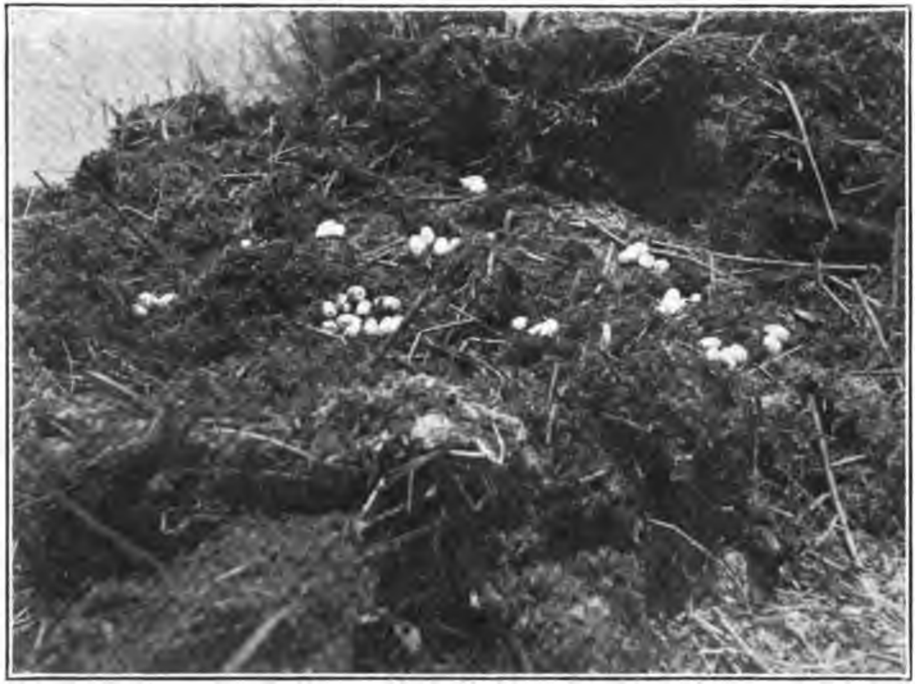
LONG-EARED SUNFISH OVER NEST. STATION 4.



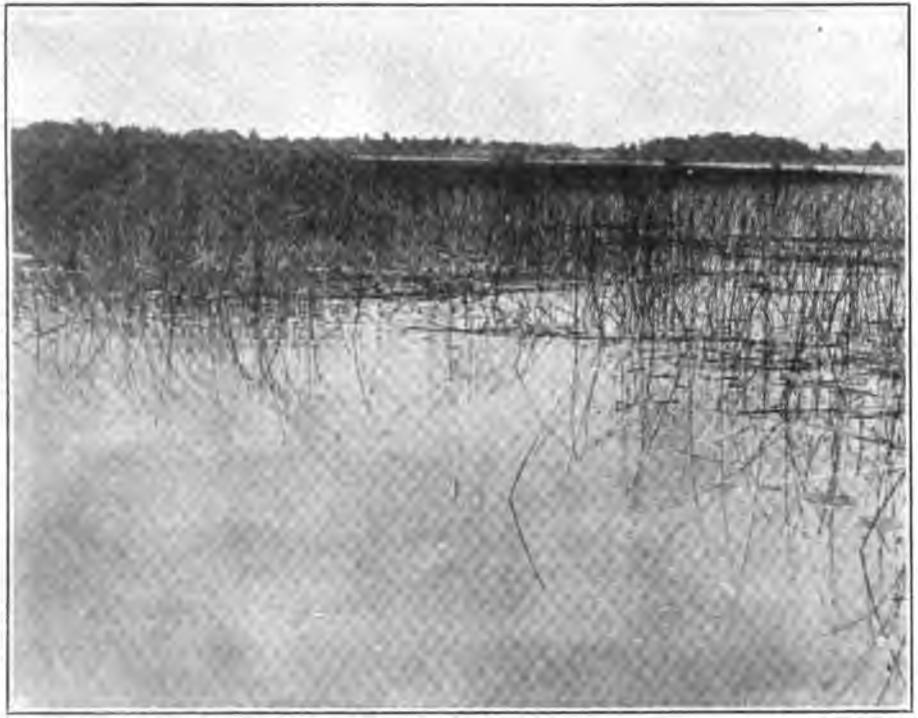
SWAMP LOOSESTRIFE SHOWING BRANCHES DROOPING IN WATER. STATION 26.



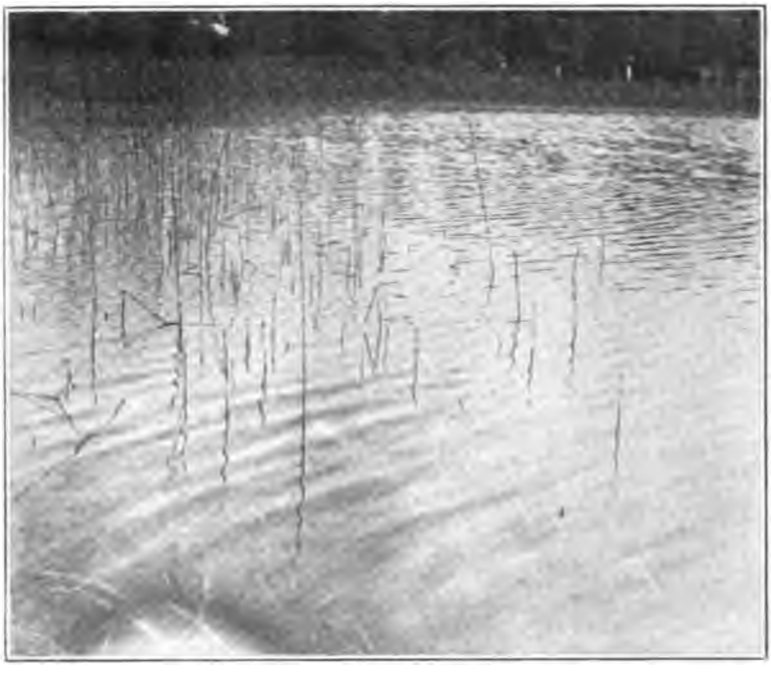
SWAMP LOOSESTRIFE, SHOWING ROOTS ON A DROOPING BRANCH.



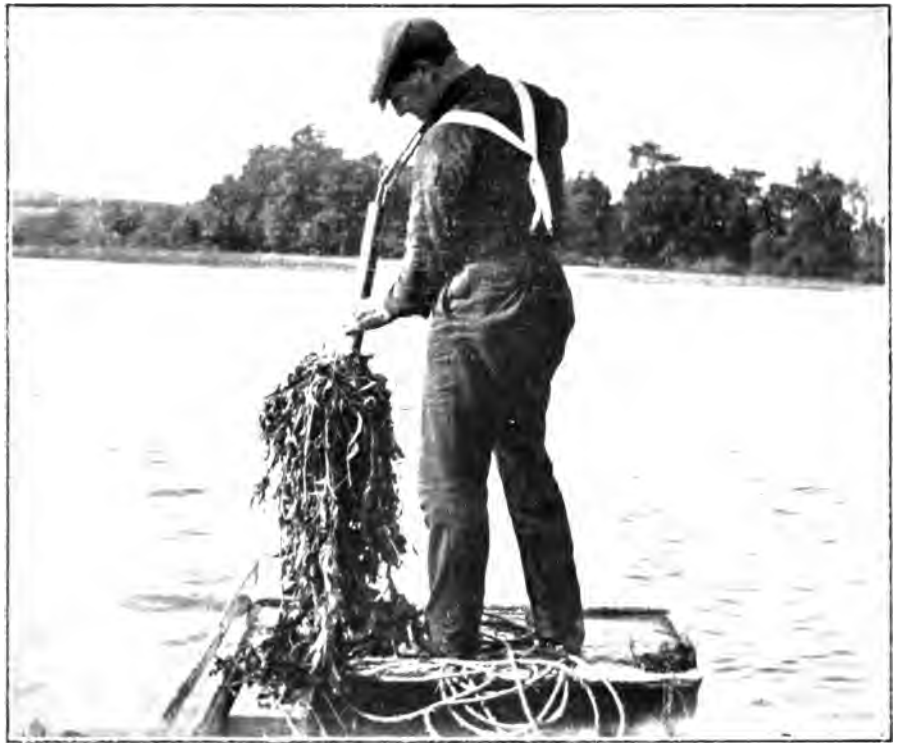
EGGS OF MUSK TURTLE IN MATERIAL OF MUSKRAT HOUSE. AS PLACED BY TURTLE BUT UNCOVERED.



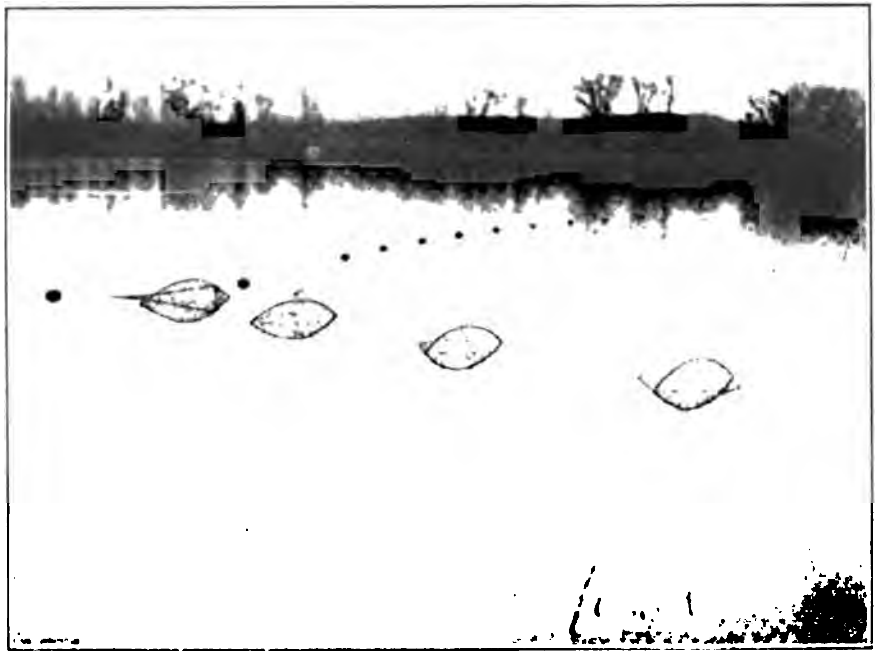
FLOATING RUSHES GATHERED IN RAFTS; POSSIBLY FORMED BY MUSKRATS. STATION 54.



BULRUSHES CUT OFF NEAR WATER SURFACE, APPARENTLY BY MUSKRATS.



A HAUL WITH THE PLANT HOOKS.



LOW FYKE NET, SET IN SHALLOW WATER.